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Life History of the Goosefish, Lophius americanus

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LIFE HISTORY OF THE GOOSEFISH, *LOPHIUS AMERICANUS*

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In Partial Fulfillment

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Master of Arts

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by

Michael P. Armstrong

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of

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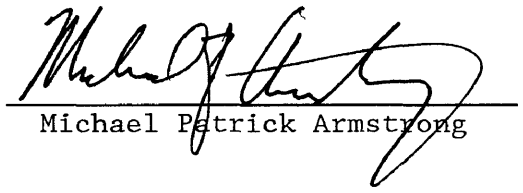

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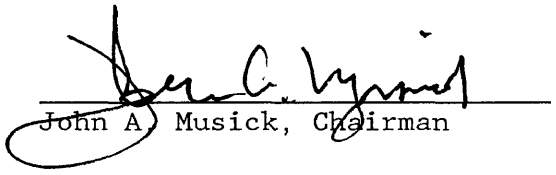

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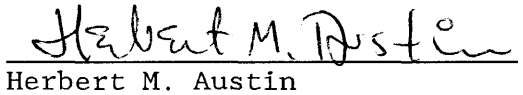

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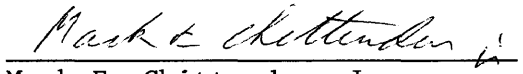

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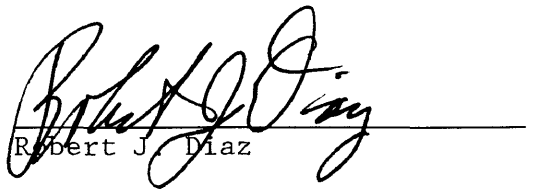

Robert J. Diaz

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ABSTRACT

Goosefish, Lophius americanus, were collected from NMFS groundfish surveys and commercial fishing cruises primarily between George's Bank and Cape Hatteras. These specimens were examined with regards to food habits, age and growth, and reproduction.

Stomach content analysis indicates that goosefish larger than 200 mm TL are almost exclusively piscivorous. Invertebrates, particularly the red shrimp, Dichelopandalus leptocerus, were more important in the diet of goosefish less than 200 mm TL. Goosefish feed opportunistically on a large number of fish species with red hake, Urophycis chuss, silver hake, Merluccius bilinearis, sand lance, Ammodytes sp., and little skate, Raja erinacea particularly important.

Age and growth of L. americanus was determined using vertebral annuli. Annuli become visible at the edge of the vertebral centra in May. Females were aged up to 11 years and males to 9. Males appear to experience higher mortality in the older age classes. Von Bertalanfy growth curves were calculated for males and females and had excellent agreement with back-calculated lengths. L. americanus exhibits a growth rate intermediate to its eastern Atlantic congeners, L. piscatorius and L. budegassa.

Male L. americanus mature at 3+ years (about 370 mm TL) and females at 4+ years (about 490 mm TL). Spawning takes place primarily in May and June. Fecundity in 17 individuals of 610 mm to 1048 mm TL ranged from 300,000 to 2,800,000 ova, and was linear with total length in that size range. Histological examination of the ovaries showed they are remarkably similar to ovaries from other species within the Lophiiform order. L. americanus produce egg veils which may function in dispersion, buoyancy, facilitating fertilization, and protection of the eggs and larvae.

LIFE HISTORY OF THE GOOSEFISH, *LOPHIUS AMERICANUS*

INTRODUCTION

The goosefish, Lophius americanus (Valenciennes in Cuvier and Valenciennes, 1837), is a benthic fish which occurs in the Northwest Atlantic Ocean from the northern Gulf of Saint Lawrence, southward to Cape Hatteras, North Carolina (Leim and Scott, 1966; Bigelow and Schroeder, 1953) and less commonly to Florida (Caruso, 1983). It has a eurybathic depth distribution, having been collected from the tideline (Bigelow and Schroeder, 1953) to approximately 840 m (Markle and Musick, 1974), although few larger individuals occur deeper than 400 m (Wenner, 1978). Goosefish have been taken in water ranging in temperature from 0-24 C^{o} (Grosslein and Azarovitz, 1982) but seem to be most abundant in temperatures of approximately 9 C^{o} in the Mid-Atlantic Bight (Edwards, 1965), 3-9 C^{o} in Canadian waters (Jean, 1965), and between 7-11 C^{o} on the continental slope off the coast of Virginia (Wenner, 1978). The goosefish is sympatric with the black-finned goosefish, L. gastrophysus, in deep water (> 100-150 m) from approximately Cape Hatteras to the Florida coast, although strays of L. gastrophysus can occur as far north as Washington Canyon, off the coast of Virginia (Armstrong, unpublished data).

Lophius americanus is closely related to L. piscatorius, a European species, and was confused with it for many years (Caruso, 1977). All references to L. piscatorius in the western North Atlantic north of Cape Hatteras actually refer to L. americanus.

There are several accounts of the species' life history (Gill, 1905; Connolly, 1920; Dahlgren, 1928; Hildebrand and Schroeder, 1928; Proctor et al., 1928; McKenzie, 1936; Bigelow and Schroeder, 1953; Leim and Scott, 1966; Grosslein and Azarovitz, 1982) but none are extensive and all are very general in nature. Much of the information contained in these reports is anecdotal.

Goosefish are a by-catch of groundfishing and scalloping operations and are marketed under the name monkfish. They have traditionally been considered "trash" fish and so discarded at sea or used in the production of fish meal, with a small amount being exported to Europe where Lophius has been highly esteemed as a food fish for centuries. Due to the dwindling catches and rising prices of the more traditional fishery products in recent years, goosefish have become more popular with the American consumer. This study describes aspects of age and growth, reproduction, and food habits of this increasingly exploited fish.

MATERIALS AND METHODS

Goosefish were collected primarily during the spring and autumn groundfish surveys (1982-1985) conducted by the National Marine Fisheries Service (NMFS) in the Mid-Atlantic Bight, Southern New England, and Gulf of Maine (Grosslein, 1969). Additional samples were obtained during the NMFS summer scallop survey (1983) off southern New England and during cruises aboard commercial groundfish trawlers and scallopers operating out of Hampton, Virginia and Gloucester, Massachusetts. Sampling effort was concentrated in the area from George's Bank to Virginia.

Goosefish greater than approximately 180 mm were examined at sea. Smaller individuals were fixed in 10% formalin and saved for examination in the laboratory. The examination included measuring total and standard length and weight, excising a section of the vertebral column, removing both sagittal otoliths, recording stomach contents, macroscopic staging and weighing of the gonads, and preserving pieces of gonads for histological inspection and/or fecundity estimates. Each of these procedures will be discussed in more detail in the following sections.

Food Habits

Each goosefish was dissected and its stomach excised. All items were identified to their lowest possible taxon. Questionable identifications were fixed in 10% formalin and returned to the laboratory for confirmation. Estimates of the volume of each prey type were made. During the NMFS Summer Scallop Cruise, the number of each prey type was also noted. Because preliminary observations indicated that goosefish often engage in extensive "net feeding", prey items found in the buccal cavity, esophagus or obviously fresh in the stomach were not used in stomach analyses. Fragments such as fish bones or crustacean parts were counted as one animal unless the fragments could be definitively assigned to multiple individuals. Volume of prey items was estimated by water displacement using a graduated cylinder (Windell, 1971) or by visual comparison of the prey items to a series of wooden dowels calibrated in milliliters (NMFS Groundfish Survey Methodology).

The relative contribution of different food items to the total diet was determined using: (1) percent frequency of occurrence (the number of stomachs in which a food item occurred expressed as a percentage of the total number of stomachs containing food); (2) percent volume (the volume of each food item expressed as a percentage of the total volume of food from all stomachs); and in the case of data from the

NMFS Summer Scallop Cruise, (3) percent numerical abundance (the number of individuals of each type of food expressed as a percentage of the total number of food items found in all stomachs).

An index of relative importance, IRI (Pinkas, 1971), which incorporates all three of these methods was calculated for each prey type recorded during the Scallop Cruise as follows:

$$IRI = (N+V)F$$

where

IRI = index of relative importance

N = numerical percentage

V = volumetric percentage

F = frequency of occurrence percentage

Goosefish were separated into four groups based on their total length (0-200 mm, 201-400 mm, 401-600 mm, and > 600 mm). IRI's were calculated for each group separately to observe ontogenetic shifts in diet.

Age and Growth

Weights were taken to the nearest gram in fish less than 1200 g and to the nearest 25 g increment in fish greater than 1200 g. Total (TL) and standard (SL) lengths in millimeters were measured from the tip of the protruding

lower jaw to the tip and base of the caudal fin rays, respectively. The base of the caudal rays were located by manually feeling for a bony protuberance present on the penultimate vertebra. Because of the large size and loose suspension of the goosefish jaw apparatus, the head was held in a standard position while length was measured to reduce variation due to head and jaw configuration. This position was achieved by applying light pressure to the top of the head, thereby causing a maximal amount of dorsal-ventral compression.

Vertebrae were chosen as the best method to age L. americanus based on a preliminary examination which revealed that each vertebral centrum contained concentric rings which appeared to be annuli. Sagittal otoliths were also examined, however, otoliths from larger fish were opaque and had extremely irregular outer margins, which made it difficult or impossible to discern annuli. Goosefish lack scales so this aging method was not available.

A section of the vertebral column containing vertebrae nos. 3-11 was excised from each goosefish. These were stored in 50% isopropanol for 1-12 months. Vertebrae nos. 7-10 were found to be similar in size and shape and also had the largest diameters. Vertebra no. 8 was selected for use in aging. If this vertebra was damaged during preparation, no. 9 was used instead.

Vertebra no. 8 was disarticulated from the rest of the excised vertebral section. The neural and haemal arches and

all excess fat, muscle, connective tissue and cartilage were removed by scalpel. The vertebra was then sliced along the mid-sagittal line producing two hourglass-shaped halves, similar to the method used by Lyczkowski (1971) and Lawler (1976) for preparing vertebrae from northern puffer, Sphaeroides maculatus, and sandbar sharks, Carcharinus plumbeus. These halves were then heated in an oven at 200 C^{o} for approximately three hours. Larger vertebra required one-half to one hour further heating. Heating in this way caused the alternating opaque and translucent bands of the vertebral centra to become more distinct.

Annuli were counted on the posterior face of the centrum. This was generally more concave than the anterior face, thus allowing greater separation of the rings. Each vertebra was read twice. If the readings disagreed, a third reading was done. Agreement between any two readings constituted the true annulus count. If all three readings differed, the vertebra was considered unreadable and not used in the analysis. A random sample of fifty vertebrae was selected for verification by an independent reader.

Measurements of the vertebral rings and radius were made from the the apex of the posterior and anterior faces of the centrum along an oblique line that followed the midline of the posterior centrum. All measurements and counts were made with a binocular dissecting scope equipped with an ocular micrometer at 10X magnification utilizing reflected light.

Regression analyses of vertebral radius on total length and weight on total length were calculated by the method of least squares. Back-calculated length at age was computed using the Lee method (Lagler, 1956):

$$L' = C + S'(L-C)/S$$

where L'= total length of the fish at time of annulus formation
L= total length of fish at time of capture
S'= measurement to the annulus
S= vertebral radius at time of capture
C= correction factor; y-axis intercept of the regression of total length on vertebral radius

Computation of the von Bertalanfy growth equations followed Ricker (1975):

$$L_t = L_\infty(1-e^{-K(t-t_o)})$$

where L_t = length at time, t
L_∞ = theoretical maximum length of fish
e = natural logarithm
K = Brody growth coefficient
t_o = theoretical time when fish length is zero

Calculations were performed on a Prime 850 computer using programs from the VIMS computer library.

Reproduction

Gonads were staged visually in the field and assigned to one of the following classes: immature, resting, developing, ripe, and spent. Both gonads were then removed from the body cavity and weighed to the nearest 0.1 g. A small representative piece was excised from the mid-section of selected gonads and preserved in Davidson's fixative for histological work-up.

Well-developed and ripe ovaries were selected for fecundity analyses. The extremely large size of goosefish ovaries precluded saving the entire organ. A subsample of approximately 100 g was weighed to the nearest 0.1 g and placed in modified Gilson's solution (Simpson, 1951). After several months of storage a majority of the ovarian connective tissue had dissolved. The ova were removed from the Gilson's solution, separated from any remaining ovarian tissue, thoroughly rinsed in water, blotted dry on absorbant paper, and weighed. Three subsamples, each containing approximately 1000 ova, were removed and weighed on an analytical balance to the nearest .001 g. The ova in each sample were counted using a dissecting scope. Diameters of thirty randomly selected ova from each sample were measured using an ocular micrometer. Fecundity was calculated according to the following formula:

$$\text{Fecundity} = (W)(P)(N)$$

where

W = total weight of both ovaries

$P = \frac{\text{wt. of sample after Gilson's}}{\text{wt. of sample before Gilson's}}$

N = mean # of ova/g from 3 subsamples

Gonad portions preserved in Davidson's fixative for histological preparations were dehydrated in a graded series of ethanol baths and Technicon reagents (S-29 dehydrant VC-670 solvent). They were then embedded in paraffin, sectioned at 7u and stained using Harris' Haematoxylin and counter-stained with Eosin Y. Gonad sections were viewed at 40X, 100X, and 400X to determine the stages of oogenesis and spermatogenesis in order to verify the accuracy of the macroscopic field staging and to examine the histology of the goosefish ovary.

A gonasomatic index (GSI) was calculated for each sex from the following equation:

$$GSI = \frac{\text{weight of gonad}}{\text{total weight of fish}} \times 100$$

RESULTS

Food Habits

Stomachs were examined from 612 goosefish. Two-hundred eighty (45.8%) of these stomachs were found to be empty. Goosefish fed mainly on fishes and to a lesser extent on benthic invertebrates. Combined results for all sizes of goosefish and from all cruises showed that fishes constituted 87.5% of prey volume and 74.2% of prey occurrences (Table 1). A total of 39 species of fish and 7 species of invertebrates were found as prey items.

By volume, the ten most important prey items were: goosefish, L. americanus (13.6%); unidentified (well-digested) teleost remains (11.0%); long-finned squid, Loligo pealeii (10.3%); Atlantic cod, Gadus morhua (8.4%); little skate, Raja erinacea (7.7%); red hake, Urophycis chuss (7.0%); silver hake, Merluccius bilinearis (7.0%); sand lance, Ammodytes sp. (5.8%); butterfish, Peprilus triacanthus (3.7%); and ocean pout, Macrozoarces americanus (3.7%).

TABLE 1

RELATIVE FREQUENCY OF OCCURRENCE AND VOLUME OF ORGANISMS FOUND IN THE STOMACHS OF *LOPHIUS AMERICANUS* - ALL CRUISES

Food Item	Percent Occurrence	Percent Volume
Ctenophore	0.3	0.02
Mollusca		
Cephalopoda		
Loligo pealeii	7.6	10.3
Unidentified squid	2.9	1.0
Total Cephalopoda	10.5	11.3
Crustacea		
Decapoda		
Dichelopandalus leptocerus	16.4	0.4
Crangon septemspinosus	2.9	0.05
Penaeus sp.	0.3	0.1
unidentified shrimp	1.2	0.1
Total Decapod	20.8	0.65
Animal Remains	2.4	0.5
Chordata		
Chondrichthyes		
Squalus acanthias	0.3	0.1
Raja erinacea	3.8	7.7
Raja sp.	0.3	0.5
Osteichthyes		
Conger oceanicus	1.2	0.2
Opichthus cruentifer	1.2	0.6
unidentified anguilliformes	1.8	0.2
Clupea harengus	0.3	0.5
Chloropthalmus agassizi	0.3	0.02
Lophius americanus	1.5	13.6
Gadus morhua	0.6	8.4
Merluccius bilinearis	3.2	7.2
Merluccius albidus	0.9	1.8
Urophycis chuss	5.6	7.2
Urophycis tenuis	0.3	0.2
Urophycis regius	0.3	0.06
Urophycis sp.	1.2	0.5
Enchelyopus cimbrius	1.5	1.9

Table 1 (Continued)

Food Item	Percent Occurrence	Percent Volume
Lepophidium cervinum	1.5	1.0
Ophidium marginatum	0.6	0.9
Macrozoarces americanus	0.9	3.5
Centropristes striata	0.3	0.4
Stenotomus chrysops	1.2	0.7
Bairdiella chrysura	0.6	0.4
Cynoscion regalis	0.3	0.4
Leiostomus xanthurus	0.6	1.1
Micropogonias undulatus	0.3	0.7
Pholis gunnellus	0.6	0.2
Ammodytes sp.	12.0	5.8
Scomber scombrus	0.3	1.6
Peprilus triacanthus	0.9	3.7
Prionotus carolinus	0.3	0.6
Citharichthys arctifrons	2.4	0.5
Paralichthys dentatus	0.3	0.4
Paralichthys oblongus	0.6	1.1
Scopthalmus aquosus	0.3	0.4
unidentified bothidae	0.9	0.3
Glyptocephalus cynoglossus	0.6	0.6
Pseudopleuronectes americanus	1.2	2.4
unidentified pleuronectidae	1.5	0.4
unidentified pleuronectiformes	0.6	0.4
unidentified teleost juveniles	0.9	0.01
unidentified teleost	22.9	11.0
Total Chordata	74.2	87.5

N = 612
# with food = 332 (54.2%)
# without food = 280 (45.8%)

By frequency of occurrence the ten commonest prey items were: unidentified (well-digested) teleost remains (22.9%); red shrimp, Dichelopandalus leptocerus (16.4%); sand lance (12.0%; long-finned squid (7.6%); red hake (5.6%); little skate (3.8%); silver hake (3.2%); unidentified (well-digested) squid (2.9%); sand shrimp, Crangon septemspinosus (2.9%); and Gulf Stream flounder, Citharichthys arctifrons (2.4%).

Stomachs were examined from 259 goosefish taken during the NMFS Scallop Cruise. Goosefish in the 0-200mm size class had a much higher percentage of stomachs with food (90.8%) than the larger three size classes in which the percentage of stomachs containing food were approximately equal : 57.5% (201-400mm); 54.2% (401-600mm); and 57.9% (>600mm). The numerical percentage (N), volumetric percentage (V), frequency percentage (F), and IRI for each prey type is presented in Table 2. These data are presented graphically in Figure 1.

In the 0-200mm size class, the decapod shrimp, Dichelopandalus leptocerus, and the sand lance, Ammodytes sp. were the dominant prey items. D. leptocerus dominated by number, occurence and IRI. Ammodytes sp. was most important by volume. Other prey items encountered in descending order of importance (by IRI) were sand shrimp, Cragon septemspinosus; long-finned squid, Loligo pealeii; and juveniles of several species of demersal fishes. However, all of these combined were relatively insignificant

TABLE 2

RELATIVE FREQUENCY OF OCCURRENCE (F), VOLUME (V), NUMBER (N), AND INDEX OF RELATIVE IMPORTANCE (IRI) FOR PREY ITEMS OF *LOPHIUS AMERICANUS* BY SIZE CLASS (COLLECTED DURING NMFS SUMMER SCALLOP CRUISE - SOUTHERN NEW ENGLAND, 1983

	Size Range (mm)															
	0 - 200				201 - 400				401 - 600				600			
Food Item	F	V	N	IRI	F	V	N	IRI	F	V	N	IRI	F	V	N	IRI
Mollusca																
Cephalopoda																
Loligo pealeii	4.0	11.8	1.1	52	8.7	5.7	9.7	134					4.5	2.2	2.0	19
unidentified squid													4.5	0.2	2.0	10
Total cephalopod	4.0	11.8	1.1	52	8.7	5.7	9.7	134	0	0	0	0	9.0	2.4	4.0	40
Crustacea																
Decapoda																
Dichelopandalus leptocerus	57.6	18.9	65.0	4833												
Crangon septemspinosus	9.1	2.5	6.9	86												
Total Decapod	66.7	21.4	71.9	6230	0	0	0	0	0	0	0	0	0	0	0	0
Chordata																
Chondrichthyes																
Squalus acanthias													4.5	1.2	2.0	14
Raja erinacea					13.0	13.5	9.7	302	5.1	7.9	2.2	52	22.7	41.5	10.2	1174
Total Chondrichthyes	0	0	0	0	13.0	13.5	9.7	302	5.1	7.9	2.2	52	27.2	42.7	12.2	1502

Table 2 (Continued)

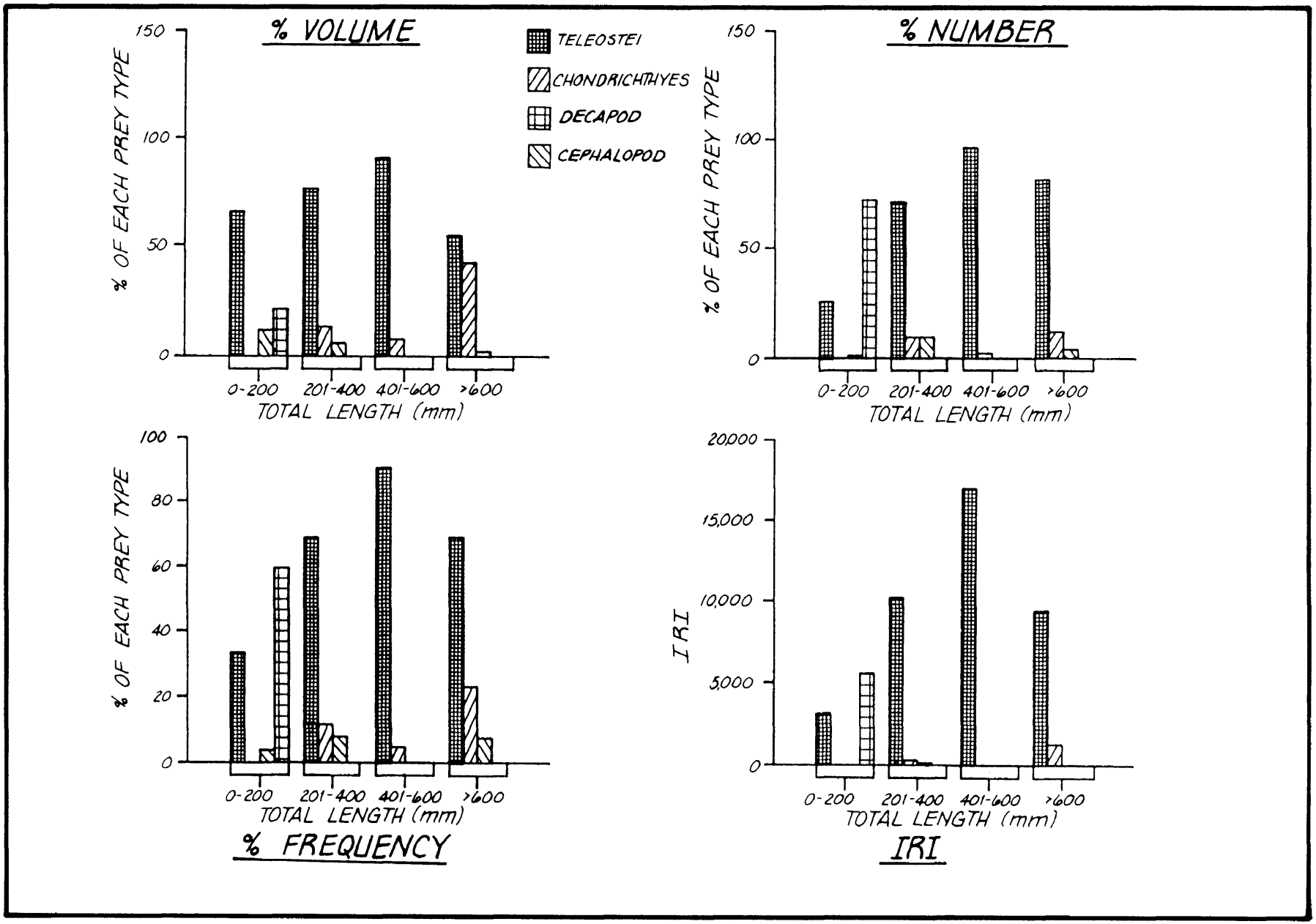
Food Item	Size Range (mm) 0 - 200 F	V	N	IRI	201 - 400 F	V	N	IRI	401 - 600 F	V	N	IRI	600 F	V	N	IRI
Teleostei																
Conger oceanicus									2.6	1.3	1.5	7				
Opichthus cruentifer									10.3	8.5	6.7	157				
Lophius americanus													9.1	9.3	2.0	103
Gadus morhua													4.5	0.8	2.0	13
Urophycis chuss	3.0	0.6	0.9	5	21.7	29.7	12.9	924	15.4	19.8	5.2	384				
Urophycis tenuis	1.0	6.6	0.3	7												
Urophycis sp.	1.0	5.8	0.3	6												
Merluccius bilinearis					4.3	14.8	6.5	92	2.6	1.6	0.7	6				
Lepophidium cervinum					4.3	4.6	3.2	34	7.7	5.8	3.0	68				
Pholis gunnellus					8.7	5.7	6.5	106								
Ammodytes sp.	21.2	41.0	20.6	1300	4.3	4.6	16.1	89	23.1	38.1	67.4	2437	22.7	6.0	51.0	1294
Peprilus triacanthus													4.5	10.8	8.2	86
unidentified bothid	1.0	0.2	0.3	1												
unidentified flatfish									2.6	2.8	1.5	11				
Paralichthys oblongus					4.3	9.1	3.2	53								
Citharichtys arctifrons	3.0	4.1	0.9	15	4.3	1.1	3.2	18	7.7	4.8	2.2	54				

Table 2 (Continued)

Size Range (mm)

Food Item	0 - 200 F	0 - 200 V	0 - 200 N	0 - 200 IRI	201 - 400 F	201 - 400 V	201 - 400 N	201 - 400 IRI	401 - 600 F	401 - 600 V	401 - 600 N	401 - 600 IRI	600 F	600 V	600 N	600 IRI
Pseudopleuronectes americanus	4.0	3.1	1.7	19									4.5	15.5	2.0	79
Unidentified teleost	3.0	4.1	0.9	15	26.1	7.0	19.4	689	28.2	8.4	8.1	465	36.4	12.4	16.3	1045
Total teleostei	37.2	65.5	25.9	3780	78.0	76.6	71.0	11,557	100.0	91.1	96.3	18,730	81.7	54.8	81.5	11,329
Animal Remains	4.0	1.2	1.1	9	4.3	3.4	3.2	28	5.1	1.1	1.5	153	0	0	0	0
# Stomach Examined		109				40				72				38		
With Food Present		99 (90.8%)				23 (57.5%)				39 (54.2%)				22 (57.9%)		

Figure 1. Percent volume, number, and frequency and index of relative importance for prey types of *Lophius americanus*.


% VOLUME
TELEOSTEI
CHONDRICHTHYES
DECAPOD
CEPHALOPOD
% OF EACH PREY TYPE
150
100
50
0
0-200
201-400
401-600
>600
TOTAL LENGTH (mm)
% NUMBER
% OF EACH PREY TYPE
150
100
50
0
0-200
201-400
401-600
>600
TOTAL LENGTH (mm)
% OF EACH PREY TYPE
100
80
60
40
20
0
0-200
201-400
401-600
>600
TOTAL LENGTH (mm)
% FREQUENCY
IRI
20,000
15,000
10,000
5,000
0
0-200
201-400
401-600
>600
TOTAL LENGTH (mm)
IRI

in the diet compared to the importance of D. leptocerus and Ammodytes sp.

Invertebrates were much less important in the 201-400 mm size class. The only invertebrate that occurred in significant amounts was L. pealeii. Teleosts were the most important prey items with red hake and unidentified, well-digested teleost remains having the highest IRI's. Little skate also occurred in small amounts.

No invertebrates occurred in stomachs from goosefish of the 401-600 mm size class. The diet was exclusively piscivorous, greatly dominated by teleosts but with a small amount of chondrichthyes also occurring. The most important prey items were sand lance, red hake, and well-digested teleost remains.

Goosefish in the greater than 600 mm class also primarily preyed on teleosts. Of the teleost remains which could be identified, sand lance was the most common. Little skate was a much more important prey item than in the smaller size groups, having an IRI second only to sand lance.

Reproduction

External sexual dimorphism was not apparent in L. americanus. Caruso (1975) noted sexual differences in nostril morphology but this was not a useable field character. Sex was easily determined in mature individuals

by examination of the gonads, which are markedly different in appearance. Gonads from small juveniles (less than approximately 160-180 mm T.L.) were indistinguishable macroscopically. Both testes and ovaries from these juveniles were small, translucent and string-like.

In females larger than approximately 180 mm T.L. the ovaries were long, wide and ribbon-like. They were greatly coiled in the abdomen and supported by an extensive mesovarium (Figure 2). The two ovaries were fused at their posterior ends, forming a single, confluent organ. The dimensions of the ovary varied greatly depending on the stage of sexual development of the female.

The testes of goosefish were solid, sausage-like organs (Figure 3). A groove was present along the medial aspect of each testis. This groove contained blood vessels and served as the site of attachment for mesentary connective tissue.

A physical description of the gonads in the five developmental stages (immature, resting, developing, ripe and spent) is presented in Table 3.

Fecundity

Fecundity in 17 individuals of 610 mm to 1048 mm TL ranged from 301,150 ova to 2,780,632 ova (Table 4). Fecundity increased linearly with total length in that size range (Figure 4). The regression of number of ova on total

Figure 2. Ovaries of Lophius americanus.

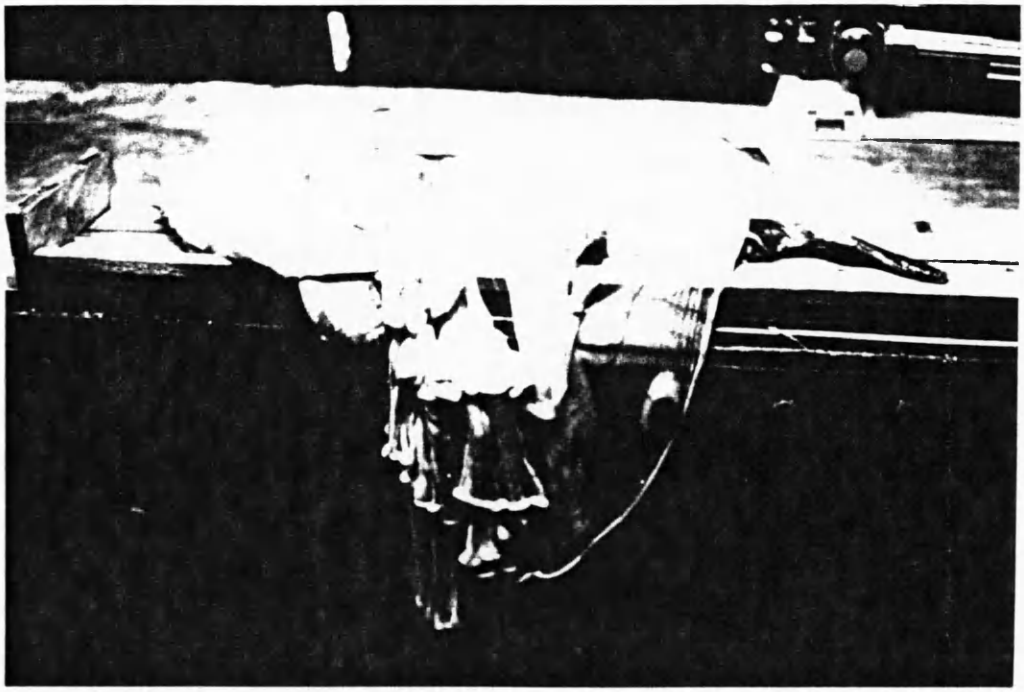


Figure 3. Testes of Lophius americanus.

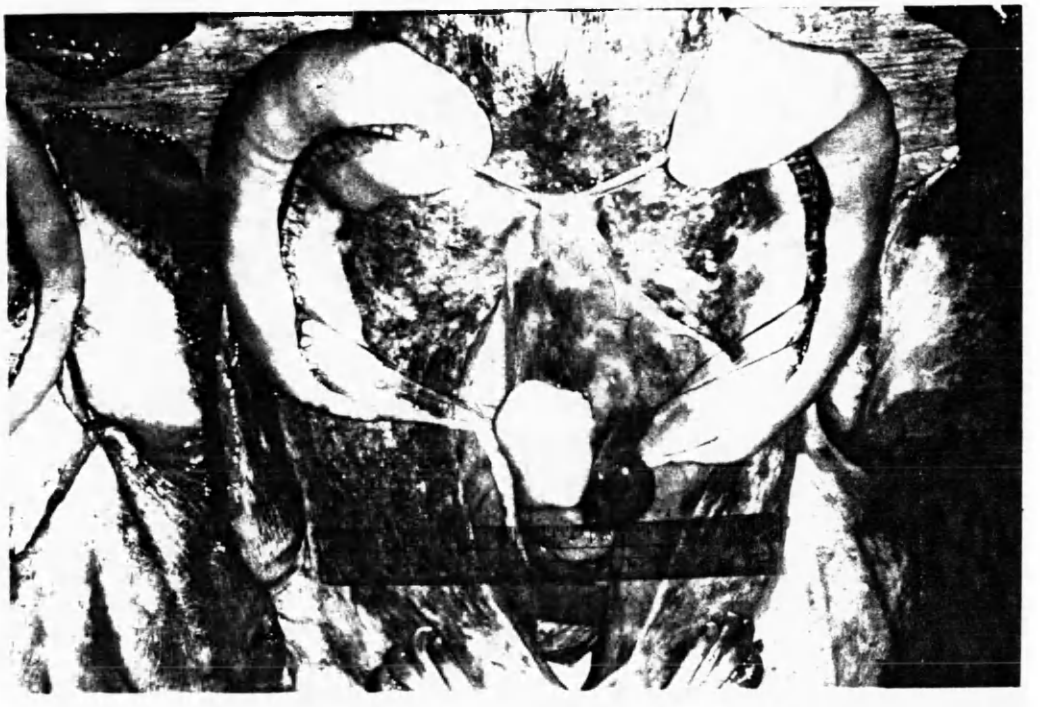


TABLE 3

DESCRIPTION OF GONADS

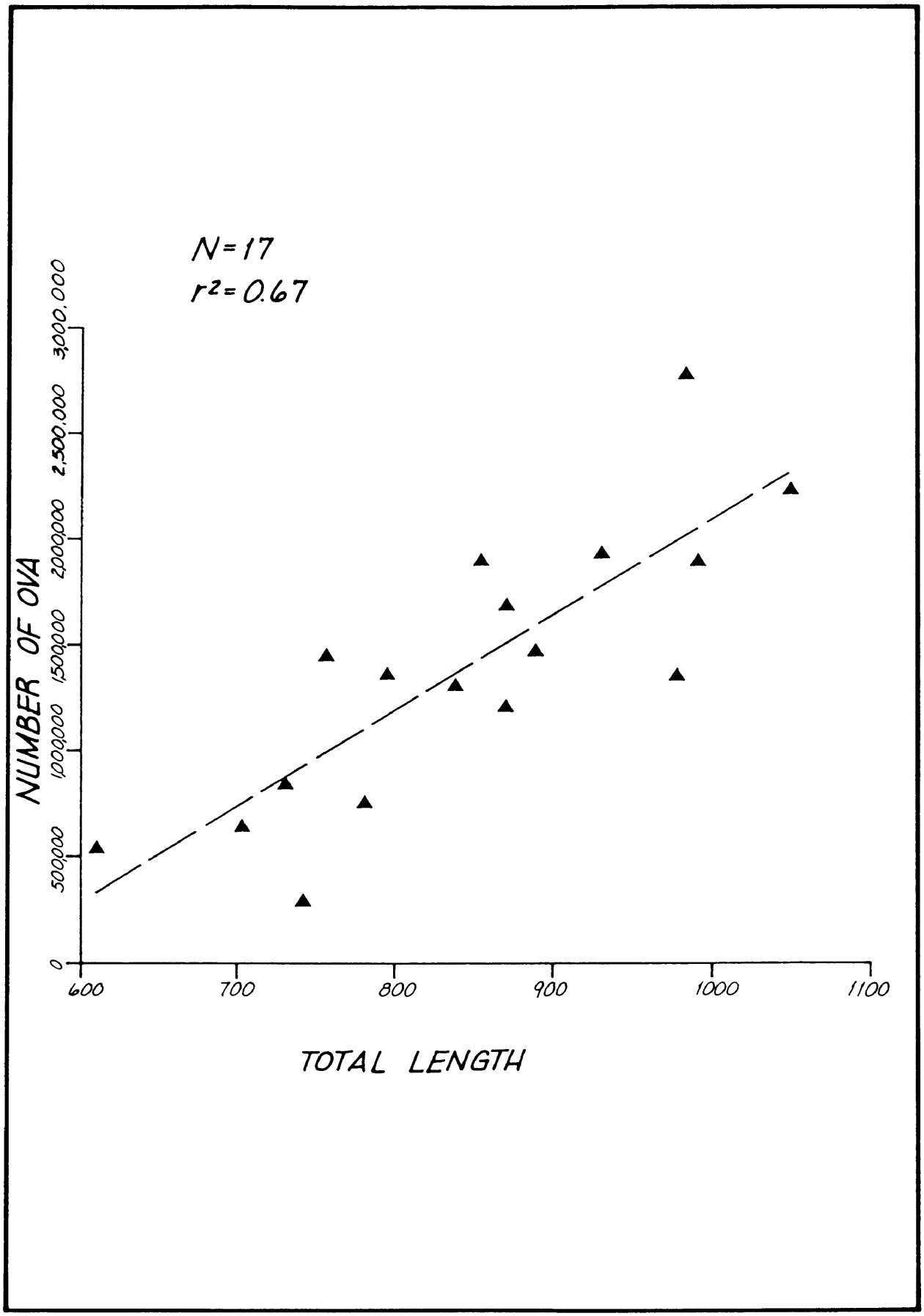
	<u>Ovaries</u>
Immature	grayish-pink, relatively small, ribbon-like, appear almost empty, no vascularization
Resting	orangish-pink, contain material but no ova visible, larger than immature, little vascularization
Developing	pink, ova discernible by eye, abdominal cavity slight bulging, higly vascular
Ripe	straw-colored to almost clear as ovary approaches spawning, distinct ova present, abdominal cavity greatly bulging, highly vascular
Spent	gray, extremely flaccid, appear almost empty, atretic ova appear as black or white dots, moderately vascular
	<u>Testes</u>
Immature	white to tan, similar in shape as mature teste but very small, medial groove less distinct
Resting	white to tan, much larger than immature, medial groove distinct, small amount of milt sometimes present when dissected
Developing	blotchy cream to tan, moderate to large amount of milt produced when dissected, very firm in texture
Ripe	blotchy cream to tan with areas of pink, extremely firm in texture, milt produced from genital pore when pressure is applied on abdomen, copious amounts produced when dissected
Spent	grayish-tan, edges appear translucent, extremely flaccid, small amount of milt sometimes present when dissected

TABLE 4

FECUNDITY

Total Length (mm)	# Ova	X Ova Size (mm)
610	566,249	1.03
703	647,253	1.18
730	851,121	1.20
742	301,150	1.19
756	1,450,221	0.84
780	759,567	1.76
795	1,365,550	0.67
838	1,242,839	0.73
854	1,906,870	0.73
870	1,212,811	1.62
870	1,695,164	0.91
888	1,486,701	0.84
930	1,938,490	0.80
977	1,359,130	1.12
982	2,780,632	0.84
990	1,901,463	0.86
1048	2,232,277	0.97

Figure 4. Relationship of fecundity with total length (mm).


N=17
r²=0.67
NUMBER OF OVA
0
500,000
1,000,000
1,500,000
2,000,000
2,500,000
3,000,000
600
700
800
900
1000
1100
TOTAL LENGTH

length in mm yielded the equation:

number of ova = 4495.04(T.L.)-2,403,814.8 $R^2 = 0.67$

Log transformations of one or both variables failed to provide a better fit.

Sexual Maturity

Goosefish reached sexual maturity (by macroscopic staging) between 290-450 mm for males and 390-590 mm for females (Figure 5). Linear regressions of percent mature on total length for the aforementioned size intervals yielded the following equations and values for length at 50% maturity (Figure 6):

Males

% mature = 0.647 (T.L.) - 188.402 $R^2 = 0.96$

Length at 50% maturity = 368.5 mm

Females

% mature = 0.580 (T.L.) - 232.432 $R^2 = 0.86$

Length at 50 % maturity = 487.0 mm

Gonad Condition

The seasonal progression of gonad condition is presented graphically in Figure 7. Both ovaries and testes followed

Figure 5. Relationship of percent mature with total length.

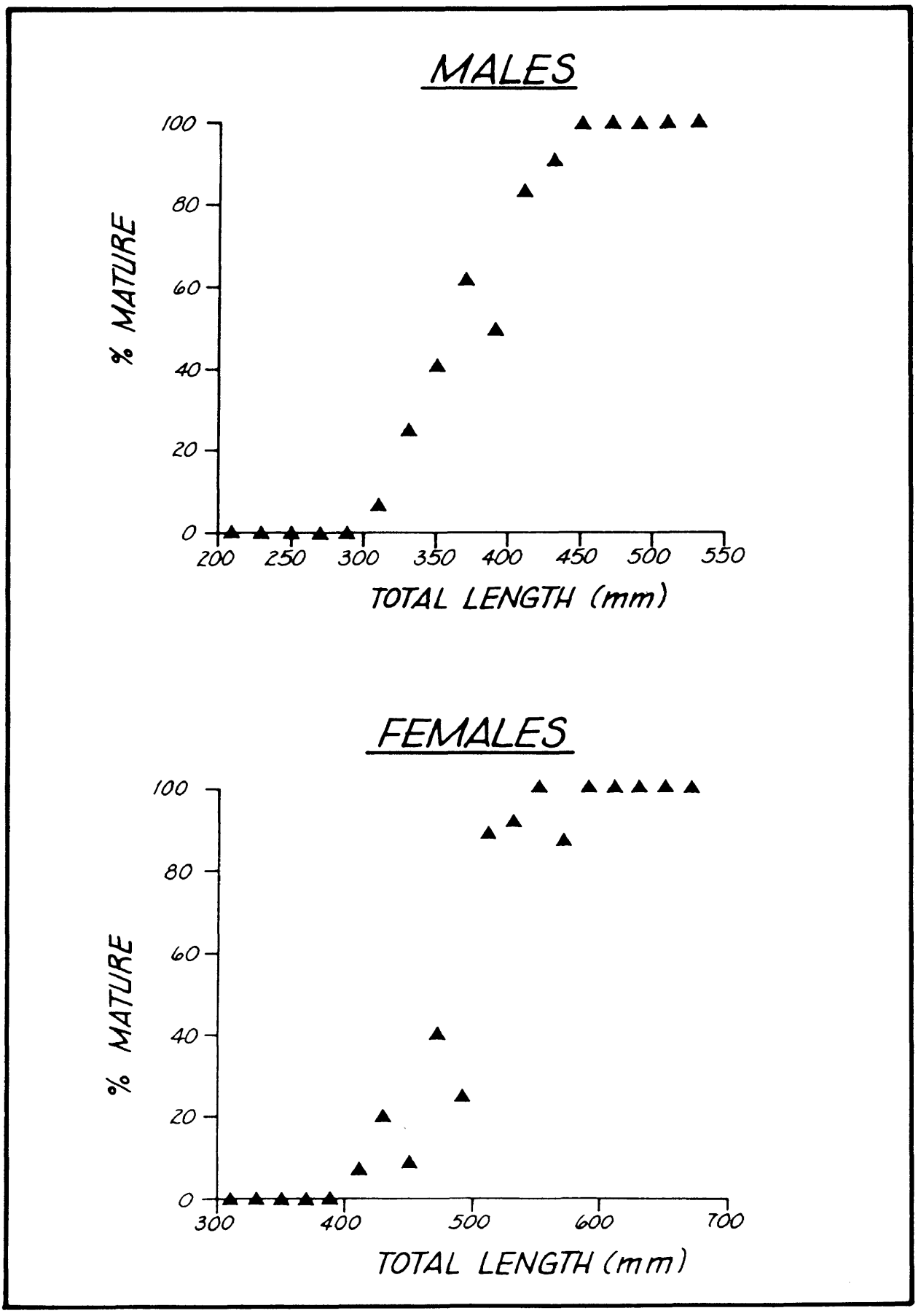
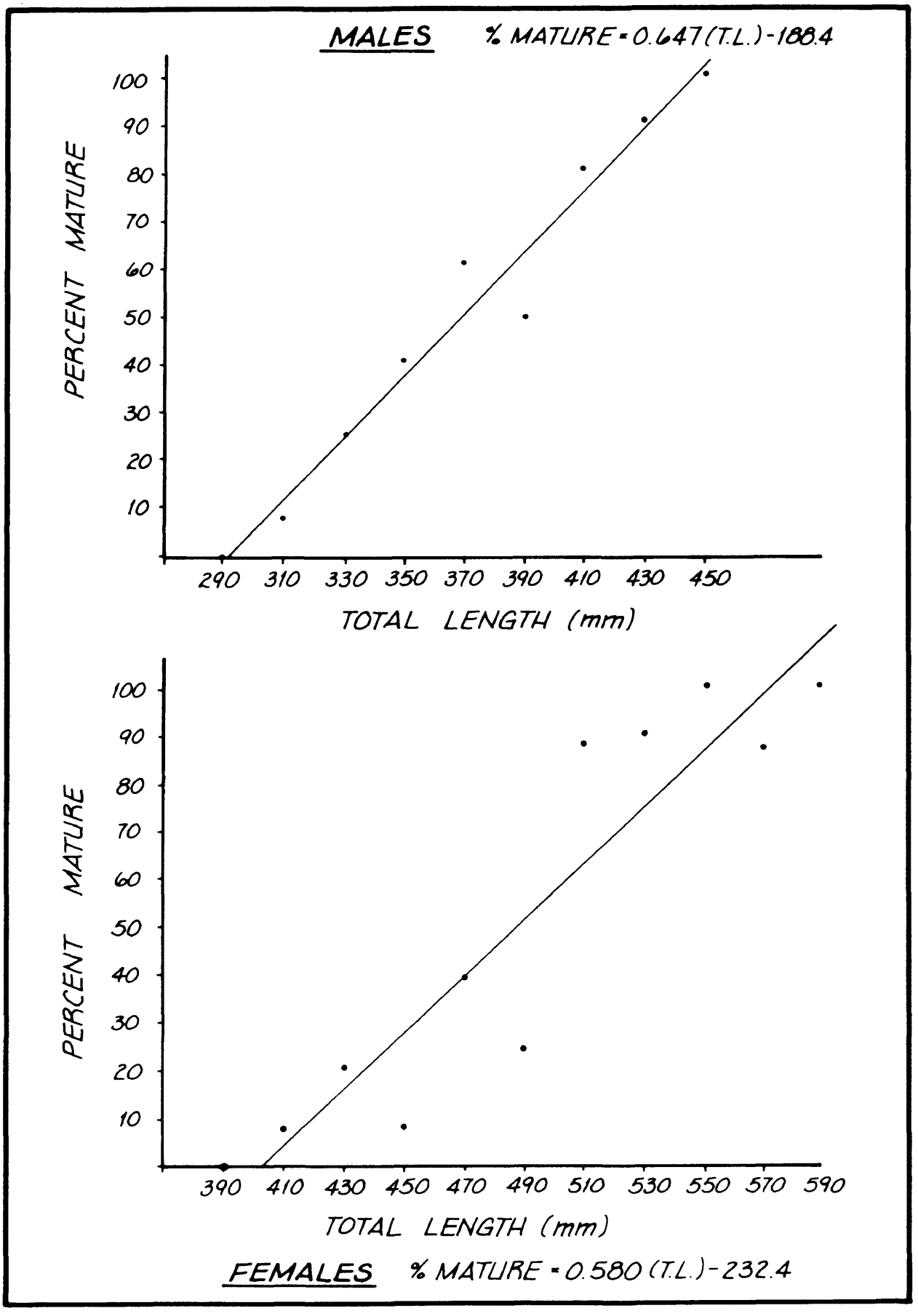

MALES
% MATURE
100
80
60
40
20
0
200
250
300
350
400
450
500
550
TOTAL LENGTH (mm)
FEMALES
% MATURE
100
80
60
40
20
0
300
400
500
600
700
TOTAL LENGTH (mm)

Figure 6. Linear regressions of percent mature on total length.


MALES
% MATURE = 0.647 (T.L.) - 188.4
PERCENT MATURE
100
90
80
70
60
50
40
30
20
10
290
310
330
350
370
390
410
430
450
TOTAL LENGTH (mm)
PERCENT MATURE
100
90
80
70
60
50
40
30
20
10
390
410
430
450
470
490
510
530
550
570
590
TOTAL LENGTH (mm)
FEMALES
% MATURE = 0.580 (T.L.) - 232.4

similar patterns of development, with the exception that testes changed from a resting to developing state earlier in the year (Jan.-Feb.). In May-June, no resting gonads were found for either sex. The percentage of spent gonads was highest in July-August, indicating that spawning had taken place in the previous time interval (May-June). Although the percentage of ripe gonads was highest in May-June, gonads in a near-spawning state were also found in March-April and July-August.

Gonasomatic Index

Gonasomatic values were calculated for 117 mature males and 98 mature females. The values were plotted by two month intervals (Figure 8). No mature females were collected during the Jan.-Feb. interval.

The GSI peaks in May-June for females and March-April and May-June for males. High index values in these months correspond with the greatest incidence of ripe individuals (Figure 7). Again, similar to observations based on gonad condition, males appear to develop earlier in the season and remain ripe longer.

The ranges of GSI values for each maturity stage are presented in Table 5. Values for females were an order of magnitude greater than for males. Females exhibited a huge increase in GSI as the ovaries developed toward ripeness. The greatest value recorded in this study was 50.9, from a

Figure 7. Seasonal progresson of gonad condition.

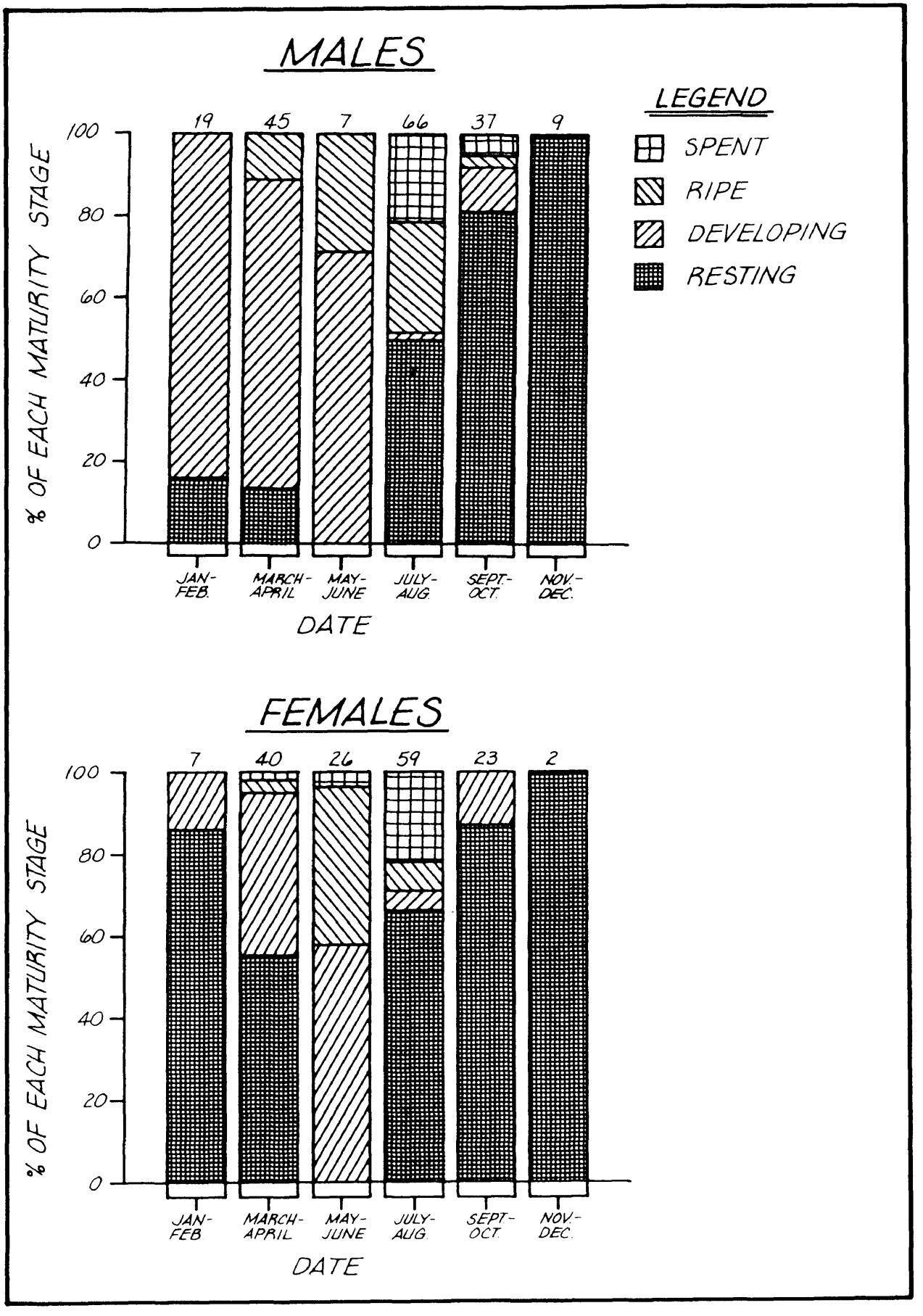

MALES
LEGEND
SPENT
RIPE
DEVELOPING
RESTING
% OF EACH MATURITY STAGE
100
80
60
40
20
0
19
45
7
66
37
9
JAN-FEB.
MARCH-APRIL
MAY-JUNE
JULY-AUG.
SEPT.-OCT.
NOV.-DEC.
DATE
FEMALES
% OF EACH MATURITY STAGE
100
80
60
40
20
0
7
40
26
59
23
2
JAN-FEB
MARCH-APRIL
MAY-JUNE
JULY-AUG.
SEPT-OCT.
NOV-DEC.
DATE

Figure 8. Seasonal progression of gonasomatic index.

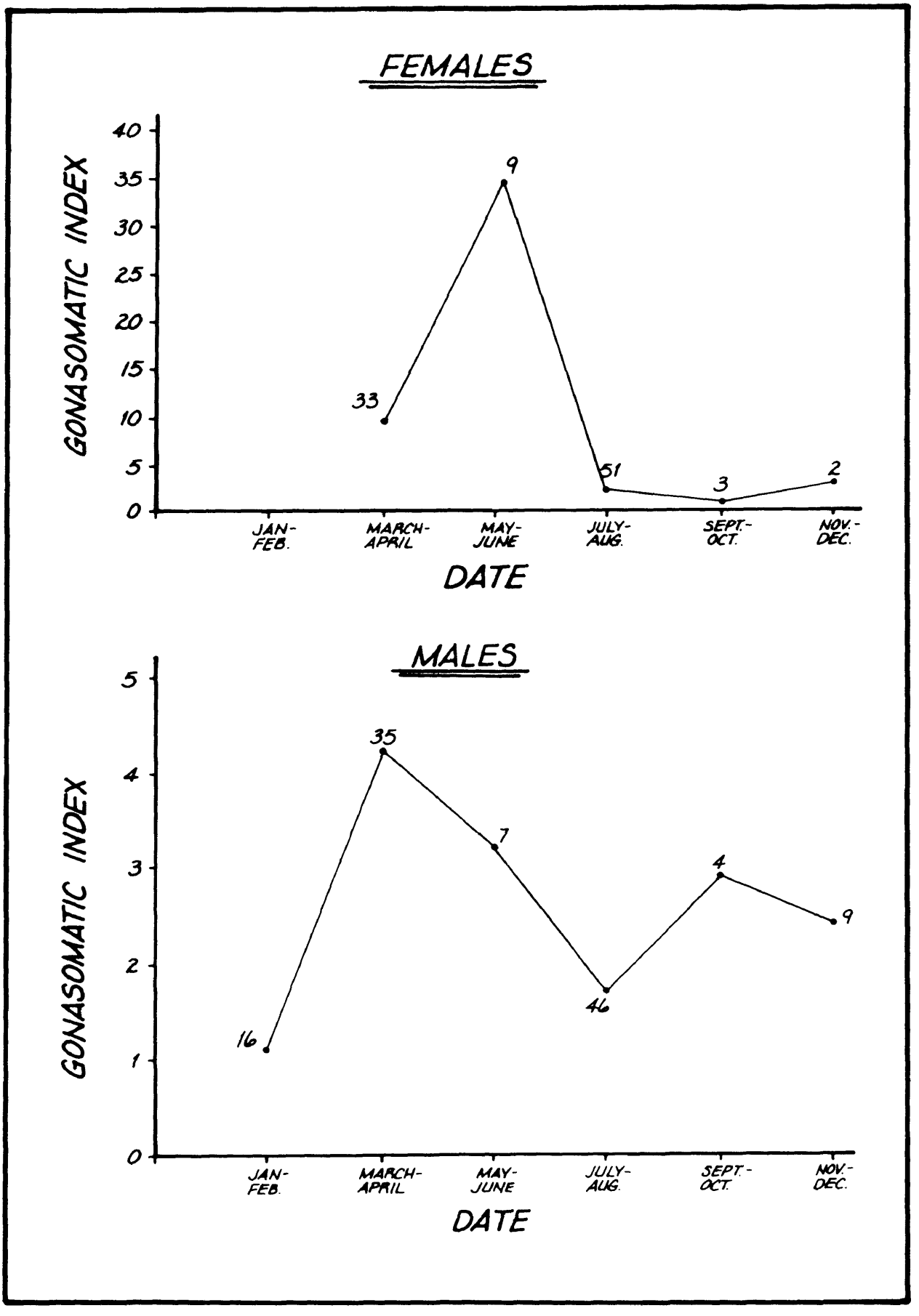

FEMALES
GONASOMATIC INDEX
40
35
30
25
20
15
10
5
0
33
9
51
3
2
JAN-FEB.
MARCH-APRIL
MAY-JUNE
JULY-AUG.
SEPT.-OCT.
NOV.-DEC.
DATE
MALES
GONASOMATIC INDEX
5
4
3
2
1
0
16
35
7
46
4
9
JAN-FEB.
MARCH-APRIL
MAY-JUNE
JULY-AUG.
SEPT.-OCT.
NOV.-DEC.
DATE

TABLE 5

Gonasomatic Index Values

	Range	X	S.D.	
Females				
Immature	Trace-1.26	--	--	N=56
Resting	0.77-7.58	2.35	1.67	N=53
Developing	3.82-22.12	12.26	5.79	N=21
Ripe	18.23-50.90	33.96	11.71	N=13
Spent	0.94-3.77	2.56	1.67	N=12
Males				
Immature	Trace-0.83	--		N=37
Resting	0.31-3.42	1.46	0.98	N=36
Developing	0.46-6.18	2.44	1.48	N=43
Ripe	0.84-5.72	3.20	1.03	N=23
Spent	0.18-4.19	1.16	0.96	N=21

ripe female. This value indicates that greater than one-half of the body weight was composed of ovarian mass.

However, only a relatively small percentage of the ovarian weight from late developing and ripe females was composed of ova. The actual percentage of the ovarian weight which was ova ranged from 12.9% to 33.5% for the seventeen females used for fecundity analysis. The remainder of the weight was ovarian tissue and more importantly, the muco-gelatinous matrix surrounding the ova.

Gonad Histology

Slides were prepared from sections of 33 ovaries and 20 testes. Representatives from all the developmental classes (immature, resting, developing, ripe and spent) were included.

Oogenesis proceeds through six distinguishable morphological stages similar to other fishes such as black sea bass, Centropristis striata (Mercer, 1978):

Oogonia: (4.5-11 um) densely packed, granular, deeply basophilic cells

Stage 1: small (15-50 um) oocytes with a large nucleus, single nucleolus, and small amount of basophilic cytoplasm

Stage 2: (30-200 um) previtellogenic oocytes with strongly basophilic cytoplasm and multiple nucleoli around the nucleus margin

Stage 3: (110-390 um) vitellogenesis begins with the deposition of yolk vesicles in the less darkly staining cytoplasm. A thin zona radiata can be seen in late stage 3.

Stage 4: (270-970 um) cytoplasm filled with yolk vesicles and globules, lightly staining. Zona radiata well developed and strongly acidophilic.

Stage 5: (> 600 um) mature or nearly mature oocytes, uniform in appearance due to the coalescence of yolk globules. Often fractured or irregular in outline due to fixation and sectioning. Seldom seen in histological sections.

Based on the occurrence of these oocyte stages, the ovaries from which these slides were prepared were placed in the following developmental classes:

Immature: Stage 1 and 2 oocytes present, atretic bodies absent. The ovarian lamellae are pressed tightly together and lumen is small.

Resting: Stage 1, 2, and 3 oocytes are present with stage 2 dominating.

Developing: Oocyte stages 1, 2, 3, and small 4 are present with 3 dominating.

Ripe: Oocyte stages 1, 2, 3, 4, and sometimes 5 are present with 4 dominating.

Spent: Oocyte stages 1, 2, and 3 are present with 2 dominating. Atretic stage 4 and 5 oocytes and ruptured follicles are present.

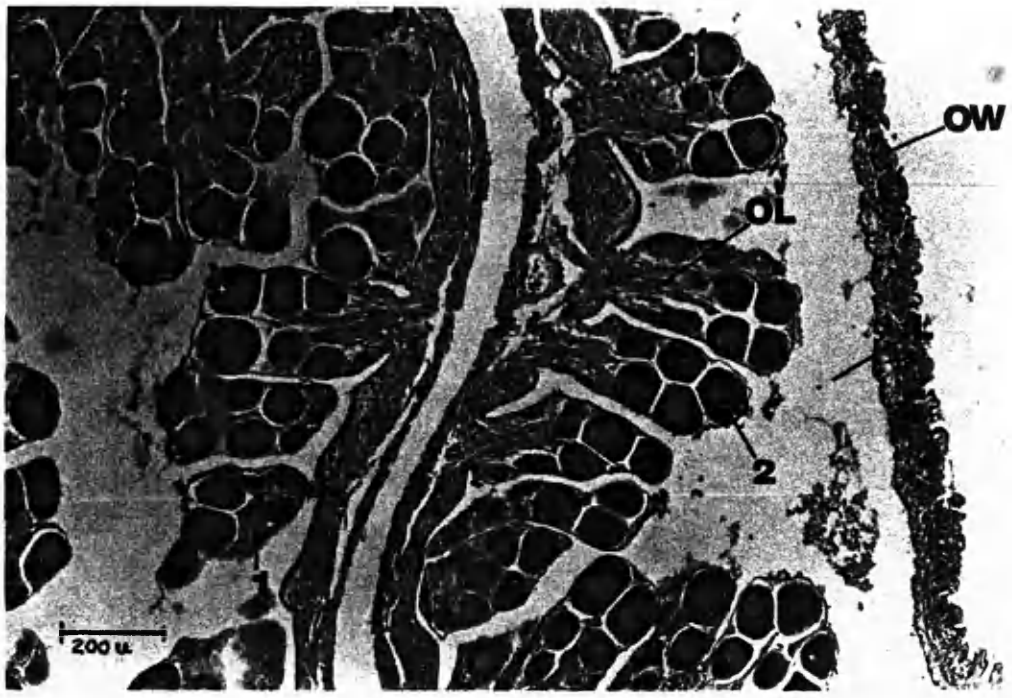
Comparisons made between the macroscopic and microscopic maturity classifications indicated excellent agreement between the two methods. Only 2 (6%) needed to be reclassified following the histological examination. These included one that was reclassified from ripe to developing, and another changed from resting to immature.

Figures 9 and 10 show the histology of the goosefish ovary. The lumen is not centrally located but is at one side. The ovigerous tissue extends into the lumen in the form of lamellae from one wall only. In late developing and ripe ovaries, the muco-gelatinous material which forms the egg veil can be seen surrounding the ovigerous lamellae and filling the lumen (Figure 10). This material is produced by the epithelial cells (Fulton, 1898) which can be seen lining the lumen and lamellae (Figure 10).

Spermatogenesis proceeds through six distinct stages analogous to those described by Hyder (1969) for Tilapia and Ross (1978) for Caulolatilus microps. These stages are primary and secondary spermatogonia, primary and secondary spermatocytes, spermatids, and spermatozoa. Spermatogenesis in goosefish is not markedly different from other teleosts so a description of the process is not provided here.

The 20 testes examined histologically were placed in the following maturity classifications based on a modification

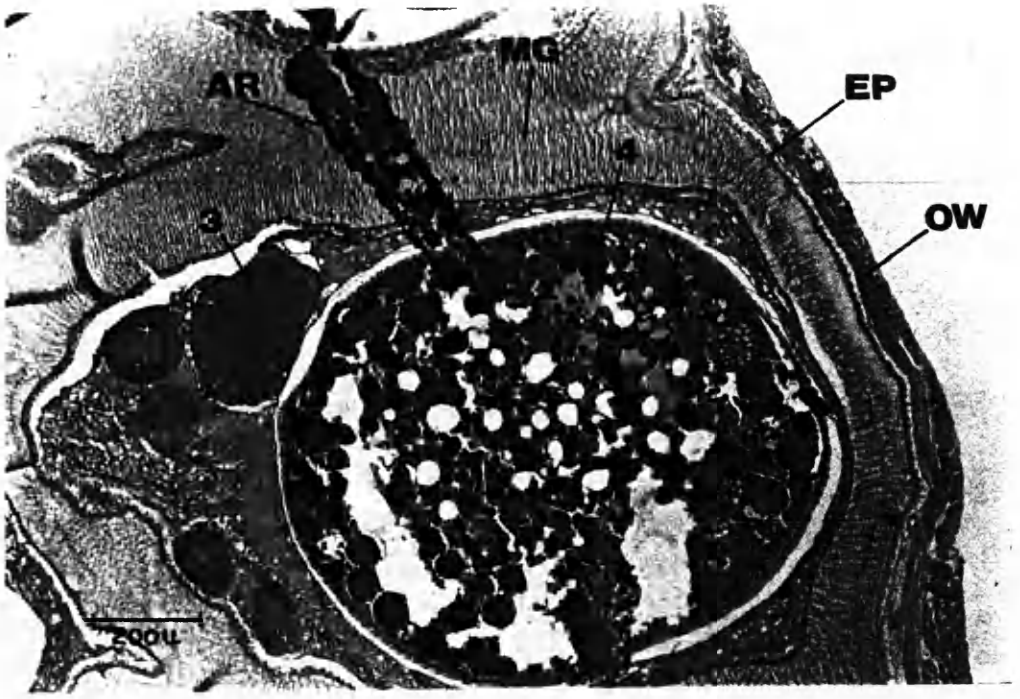
Figure 9. Histology of goosefish ovary. A. Immature ovary. Stages 1 and 2 oocytes. B. Resting ovary. Stages 1, 2, and early 3 oocytes. Abbreviations: OL, ovigerous lamellae; L, lumen; OW, non-ovigerous ovarian wall.



A

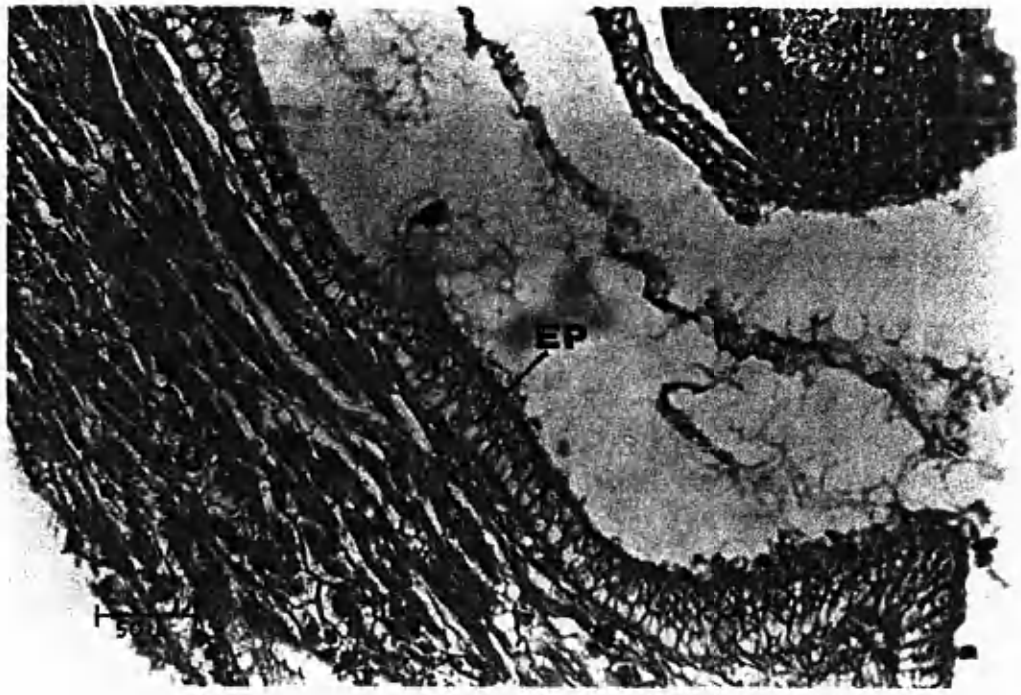
B

Figure 10. Histology of goosefish ovary. A. Late developing ovary. Stage 3 and 4 oocytes. B. Close up of epithelial lining. Abbreviations: MG, muco-gelatinous matrix; EP, epithelial lining of lumen and lamellae; OW, non-ovigerous ovarian wall; AR, artifact.



A

B



of the system of Hyder (1969):

Immature: Primary and/or secondary spermatogonia are present; primary and/or secondary spermatocytes may also be present.

Resting: Primary and/or secondary spermatogonia and spermatocytes are present. Spermatids also present. Small amount of spermatozoa may be present in lumen.

Developing: Few primary and/or secondary spermatogonia visible; primary and/or secondary spermatocytes and spermatids present; spermatozoa present in lumen.

Ripe: Few or no primary and/or secondary spermatogonia and spermatocytes visible; lumen densely packed with spermatozoa.

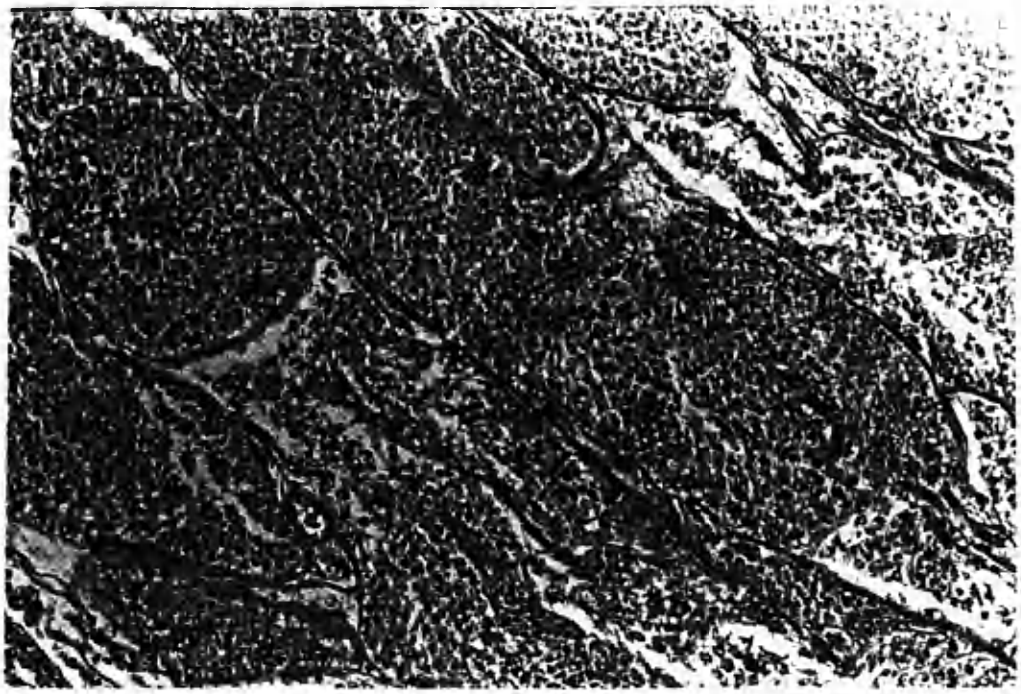
Spent: No primary and/or secondary spermatogonia or spermatocytes visible; no spermatids present; few spermatozoa remaining in lumen.

The maturity classifications based on histological examination were in agreement with the visual classifications applied in the field. Figure 11 shows the histology of the goosefish testis.

Age and Growth

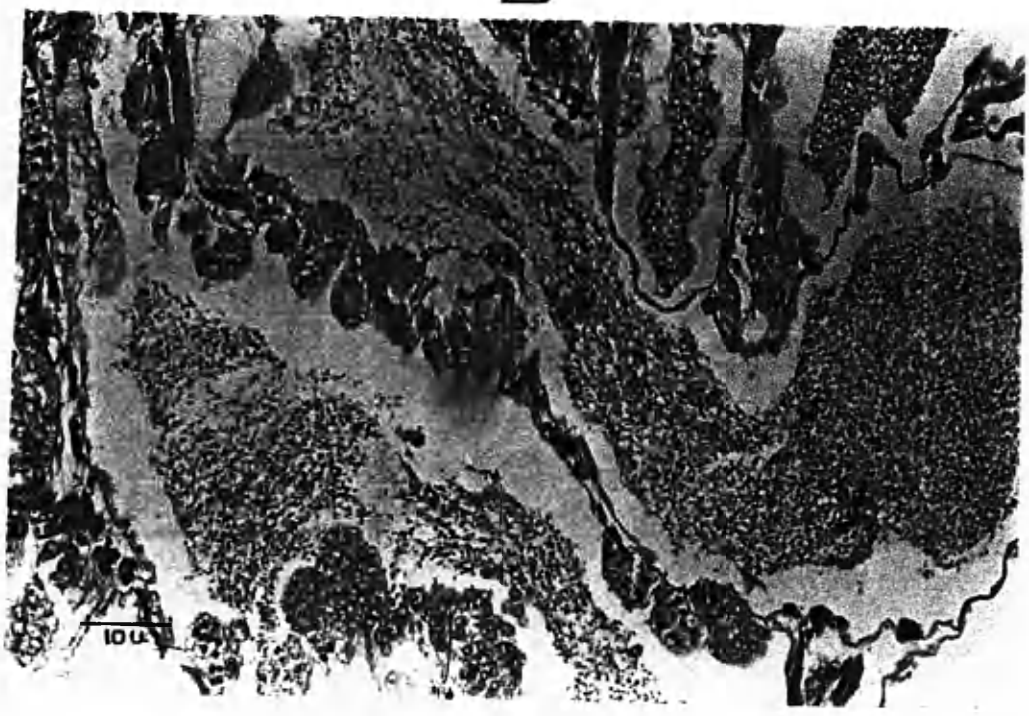
Growth marks on the vertebrae of Lophius americanus formed distinct steps on the centrum surface. Under magnification in reflected light, the surface texture of the centrum within the narrow step appeared coarser than the

Figure 11. Histology of goosefish testes.
A. Resting testis. B. Ripe testis.



A

B



rest of the centrum. On the outter side of each step was a narrow, dark, translucent band. The step and this narrow band formed a continuous ring around the centrum and constitute the annulus. Broader, lighter, opaque bands with relatively uniform surface texture were between the annuli. A broad, opaque band combined with a narrow, translucent band and step constituted one year's growth.

While these features were visible on fresh vertebrae, they became much more distinct when the vertebrae were heated. The step became deeper and the narrow, translucent band became opaque but very dark relative to the rest of the centrum. Figure 12 shows the features of several vertebrae after heating.

Annuli were counted on vertebra from 635 goosefish. In 200 (31.5%) of the cases, the first and second reading did not agree and a third reading was done. In most cases, the second reading was only off by one. In 25 (3.9%) of the cases, the third reading was different from both the first and second and so these vertebrae were considered unreadable and discarded from the analysis.

The differences between readings were due to the presence of false annuli or because the true annuli were not distinct. False annuli appeared as dark bands but were not associated with a step. Another extraneous mark that sometimes occurred was a depression which formed a continuous ring on the centrum but was not a definitive step. This feature has also been found on black bullhead

Figure 12a. Goosefish vertebra after heating. Five year old.

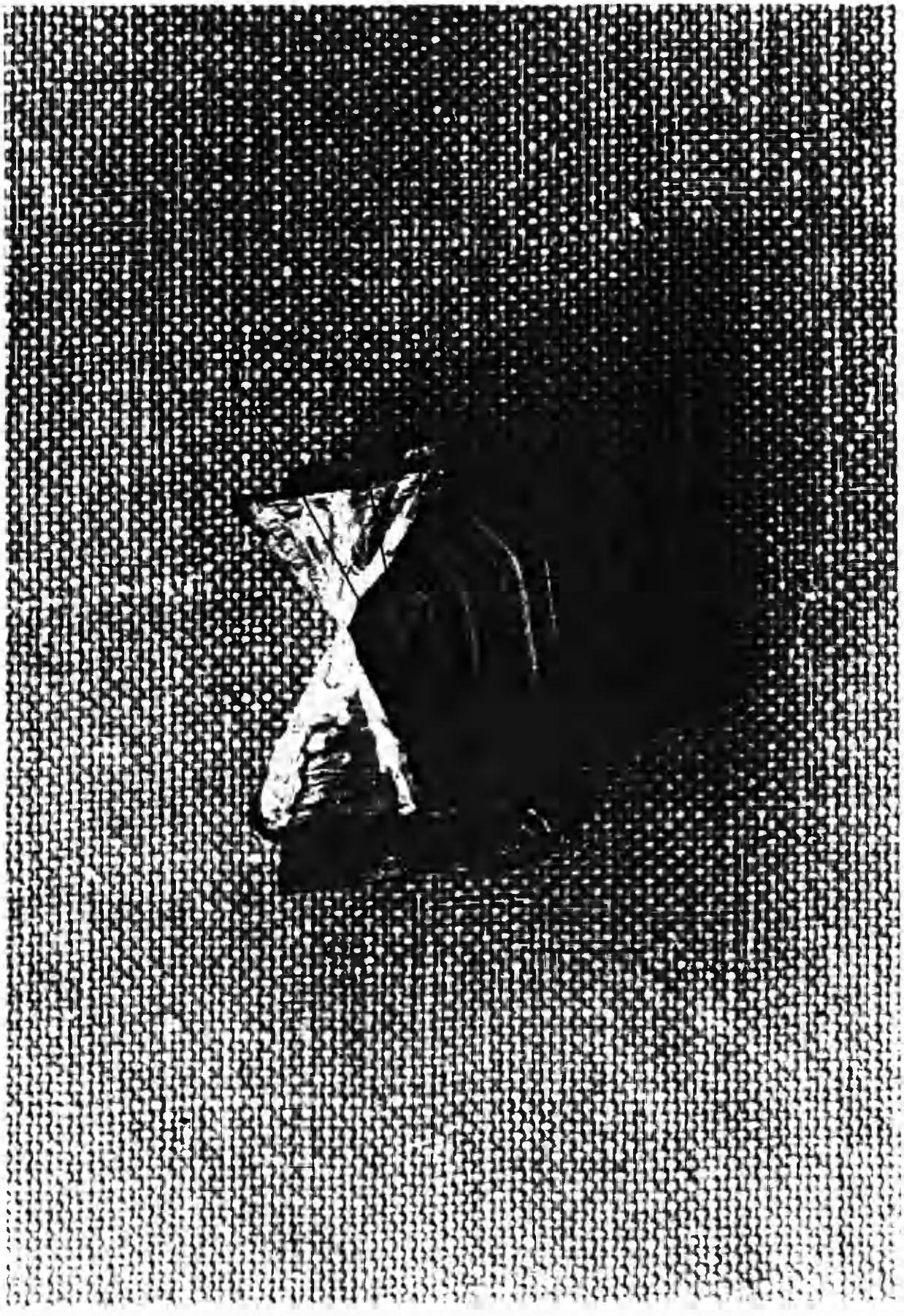
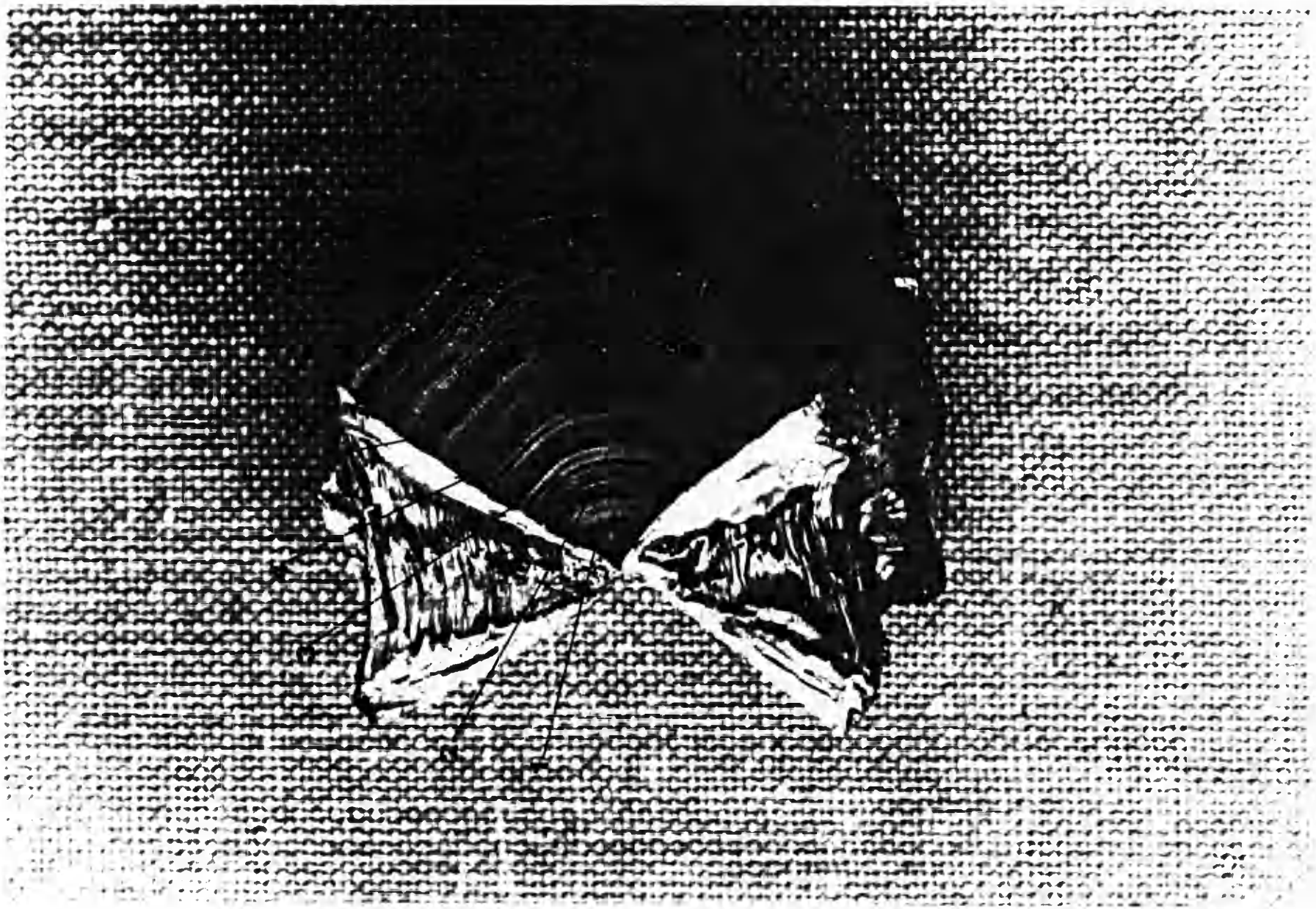


Figure 12b. Goosefish vertebra after heating. Eight year old.



(Lewis, 1949) and northern puffer (Lyczkowski, 1971) vertebrae.

A random sample of 50 vertebrae was selected to be examined by an independent reader. The annuli counts determined by the independent reader agreed with the original counts in 40 (80%) of the cases. In none of the cases was the difference in counts greater than one.

Verification of Aging Technique

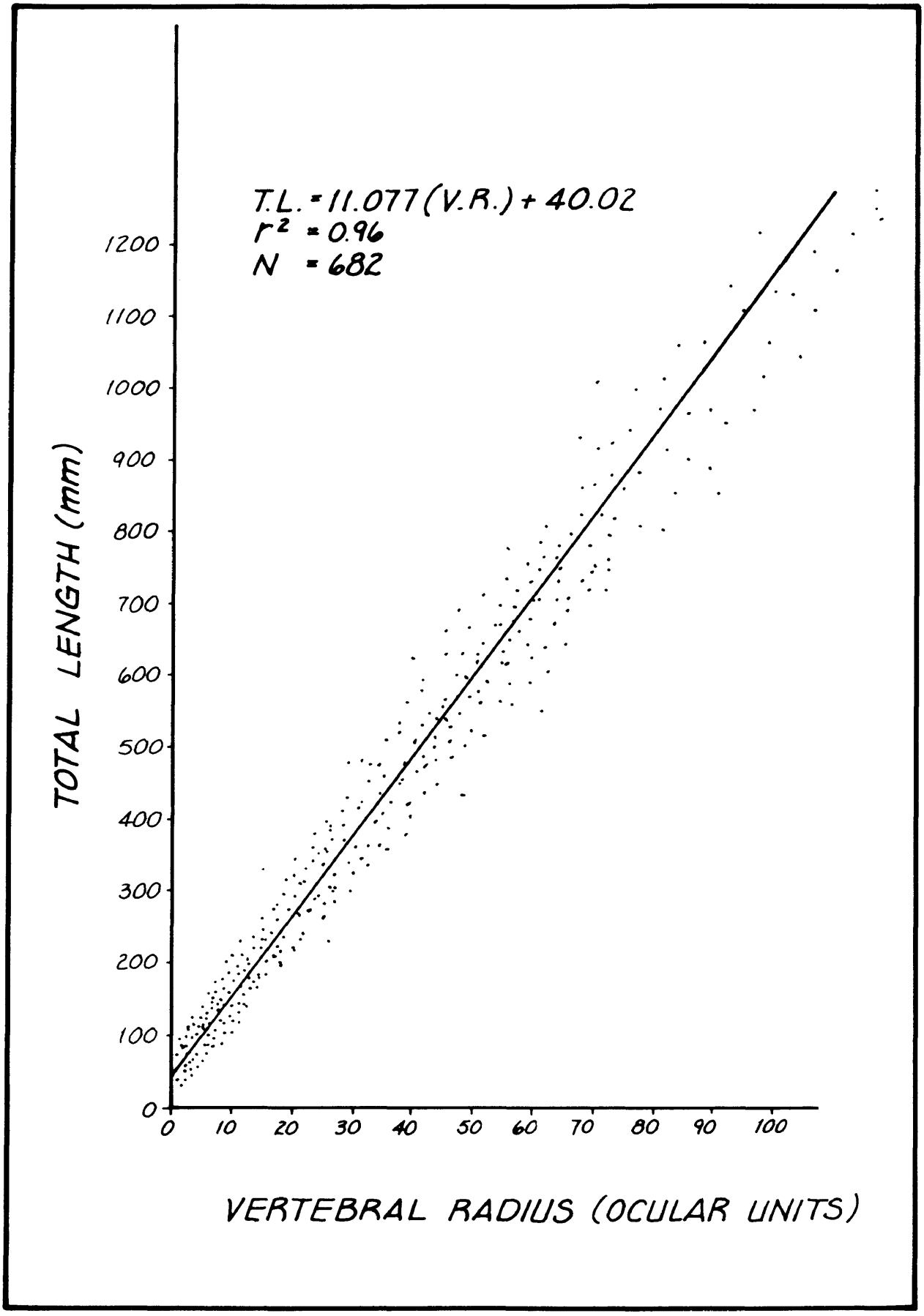
Van Oosten (1929) established the following criteria that must be met before check marks on scales or bones can be considered annuli: (1) scales or bones must remain constant in number and identity throughout the life of the fish; (2) growth of the scale or bone must be proportional to the overall growth of the fish; (3) Growth check marks must be formed at approximately the same time each year; and (4) back-calculated lengths should agree with empirical lengths.

The first criterion is obviously fulfilled by using vertebrae as the ageing tool.

The regression of total length (mm) on vertebral radius (ocular units) revealed a strong linear relationship between the two variables (Figure 13). The regression equation based on 682 vertebrae from both sexes was as follows:

$$T.L. = 11.077(V.R.) + 40.018 \qquad R^2 = 0.97$$

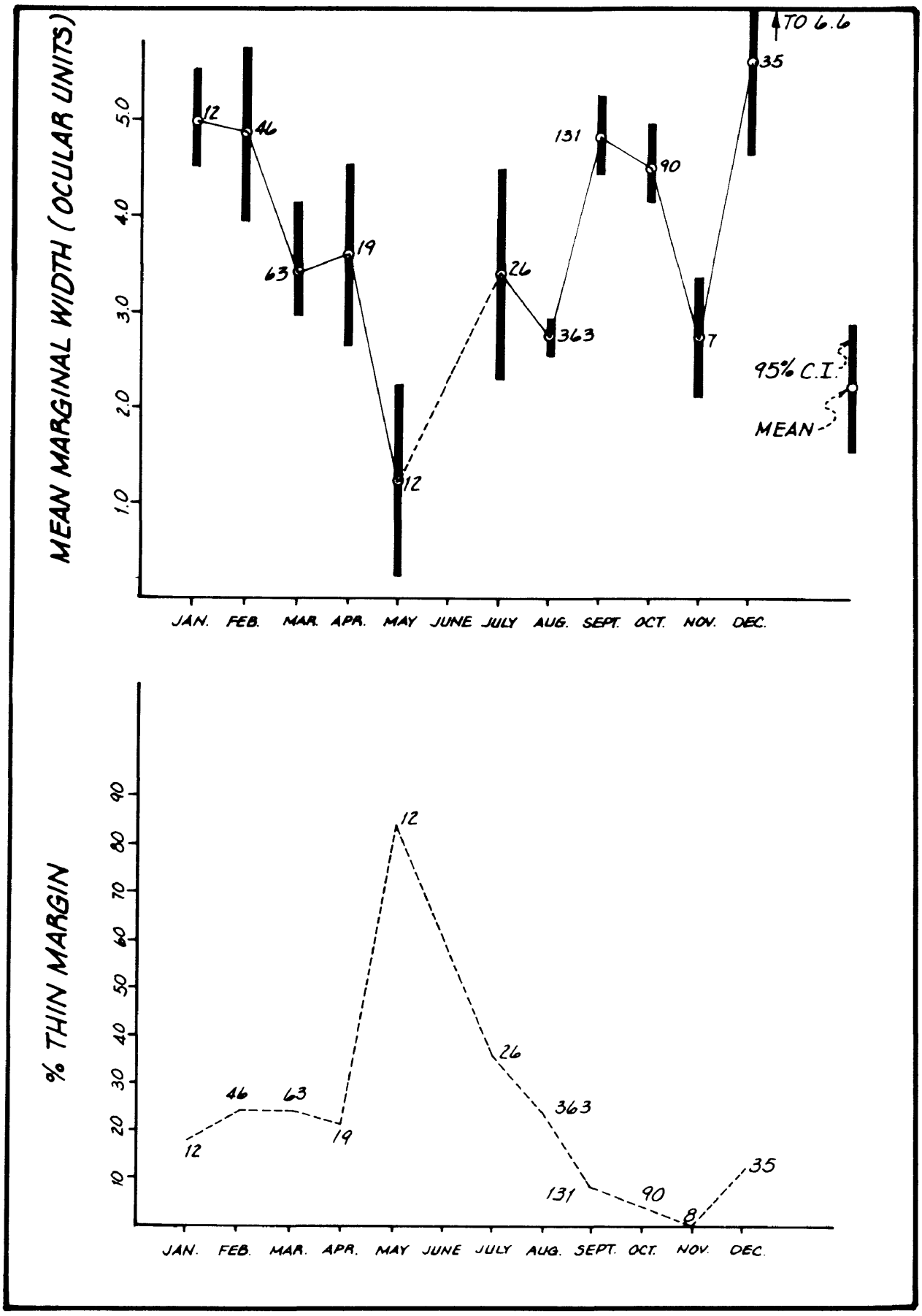
Figure 13. Linear regression of total length on vertebral radius.


T.L. = 11.077 (V.R.) + 40.02
r² = 0.96
N = 682
TOTAL LENGTH (mm)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
0
10
20
30
40
50
60
70
80
90
100
VERTEBRAL RADIUS (OCULAR UNITS)

This indicates that the growth of vertebrae is directly proportional to the growth of the fish, thereby satisfying Van Oosten's second criterion.

Monthly mean marginal increments were plotted for all age groups combined (Figure 14). Sample size was not large enough to plot the age groups separately. However, inspection of the data indicated that the seasonal progression of marginal increment was similar for all age groups. Percentage of vertebrae showing a very small marginal increment (less than 1 ocular unit), indicating that little or no growth had occurred since tha annulus was deposited, was also plotted (Figure 14). The annuli were found to be closest to the edge of the vertebrae in May. Marginal increments were highest in December through February, following a period of growth from July to December. The percent of vertebrae with thin margins showed less variation than marginal increments. The percent was highest in May and decreased as the season progressed. These plots indicate that May is the time of annulus formation, therefore fulfilling Van Oosten's third criterion that states that growth checks must be formed at approximately the same time each year. Although there was a decrease in the marginal increment from February to March, there was no corresponding rise in the percentage of very small margins (i.e. the mean value of marginal width was not being lowered by the presence of marginal widths <1).

Figure 14. A. Plot of monthly mean marginal increment. B. Percent of vertebrae with thin margin (less than 1 ocular unit)


MEAN MARGINAL WIDTH (OCULAR UNITS)
1.0
2.0
3.0
4.0
5.0
TO 6.6
12
46
63
19
12
26
363
131
90
7
35
95% C.I.
MEAN
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
% THIN MARGIN
10
20
30
40
50
60
70
80
90
12
46
63
19
12
26
363
131
90
8
35
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.

Although the relatively small sample sizes preclude making definitive conclusions, these data suggest that some process is causing the vertebrae to decrease slightly in diameter, possibly the resorbtion of the outer surfaces due to starvation in late winter.

Mean lengths were back-calculated for 256 males and 260 females. One hundred forty-two individuals, whose sex could not be determined because their gonads were undifferentiated (total length range 94-239 mm) but who were determined to have one annulus, were included in the back-calculations for each sex, bringing the total number used in the analysis to 398 and 402 males and females, respectively. These data, the observed mean lengths, and the von Bertalanfy lengths for each sex are presented in Table 6.

The observed (empirical) lengths were consistently higher for individual age groups. However the differences are within the limits of seasonal growth and related to marginal increment. Van Oosten's fourth criterion appears to have been fulfilled.

Males and females had very similar observed and back-calculated lengths-at-age until age 4 (Figure 15). Above age 4, the mean lengths for females were slightly greater than males, with the difference becoming more pronounced with increasing age (figure 16).

The data suggest a difference in maximum age for the two sexes. The oldest male collected was nine years old. Males older than six were exceptionally rare. Only one individual

TABLE 6

MEAN BACK-CALCULATED, OBSERVED AND THEORETICAL LENGTHS
OF *LOPHIUS AMERICANUS* (Total Length in mm)

FEMALES

Age	Number of Specimens	Mean observed Length	von Bertalanfy Length	Mean Back-Calculated Lengths at Successive Annuli										
				I	II	III	IV	V	VI	VII	VIII	IX	X	XI
1	163	169	121	124										
2	67	313	253	126	261									
3	44	412	373	124	257	361								
4	26	526	482	116	248	373	476							
5	27	652	581	130	278	405	507	600						
6	25	718	672	121	250	366	477	580	672					
7	17	729	754	124	265	386	485	573	662	757				
8	13	874	828	110	242	361	468	567	665	745	834			
9	14	937	896	119	250	373	475	567	652	740	821	901		
10	4	991	957	107	244	353	458	574	655	741	815	890	966	
11	2	1024	1014	117	254	380	488	591	677	757	826	894	962	1013
		Mean		123	258	374	483	581	664	748	826	898	965	1013
		Growth Increment		123	135	116	109	98	83	84	78	72	67	48

TABLE 6 (Continued)

MALES - All Ages

Age	Number of Specimens	Mean observed Length	von Bertalanfy Length	Mean Back-Calculated Lengths at Successive Annuli I	II	III	IV	V	VI	VII	VIII	IX
1	163	167	133	123								
2	78	322	256	127	267							
3	61	425	367	134	265	374						
4	49	519	469	127	263	377	472					
5	34	602	560	127	269	378	478	568				
6	10	664	644	109	241	352	465	549	634			
7	1	688	719	82	189	284	390	486	592	688		
8	1	815	788	109	255	367	473	602	675	731	793	
9	1	900	850	143	263	396	489	555	621	701	781	860
		Mean		126	264	374	473	563	633	707	787	860
		Growth Increment		126	138	110	100	90	70	74	80	73

TABLE 6 (Continued)

MALES - No Age 8 or 9

Age	Number of Specimens	Mean observed Length	von Bertalanfy Length	Mean Back-Calculated Lengths at Successive Annuli I	II	III	IV	V	VI	VII
1	163	167	125	123						
2	78	322	262	127	267					
3	61	425	378	134	265	374				
4	49	519	476	127	263	377	472			
5	34	602	559	127	269	378	478	568		
6	10	664	629	109	241	352	465	549	634	
7	1	688	689	82	189	284	390	486	592	688
		Mean Length		126	265	374	473	562	630	688
		Growth Increment		126	139	109	99	89	68	58

TABLE 6 (Continued)

MALES - No Age 7, 8 or 9

Age	Number of Specimens	Mean observed Length	von Bertalanfy Length	Mean Back-Calculated Lengths at Successive Annuli I	II	III	IV	V	VI
1	163	167	126	123					
2	78	322	261	127	267				
3	61	425	377	134	265	374			
4	49	519	477	127	263	377	472		
5	34	602	561	127	269	378	478	568	
6	10	664	634	109	241	352	465	549	634
		Mean		126	265	374	474	564	634
		Growth Increment		126	139	109	100	90	70

Figure 15a. Plot of observed, back-calculated, and von Bertalanfy lengths at age-Females.

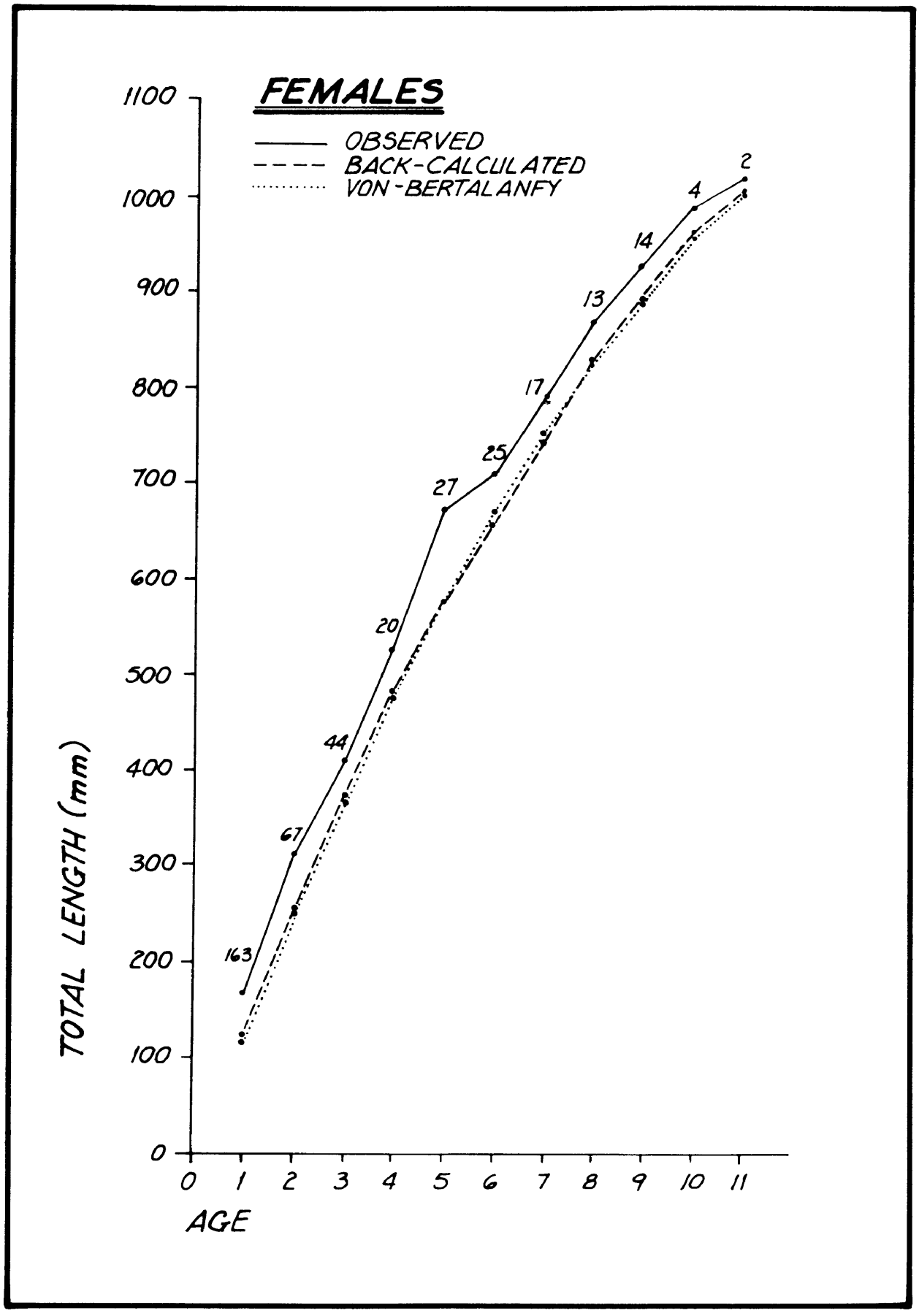

FEMALES
OBSERVED
BACK-CALCULATED
VON-BERTALANFY
TOTAL LENGTH (mm)
AGE
1100
1000
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11
163
67
44
20
27
25
17
13
14
4
2

Figure 15b. Plot of observed, back-calculated, and von Bertalanfy lengths at age-Males.

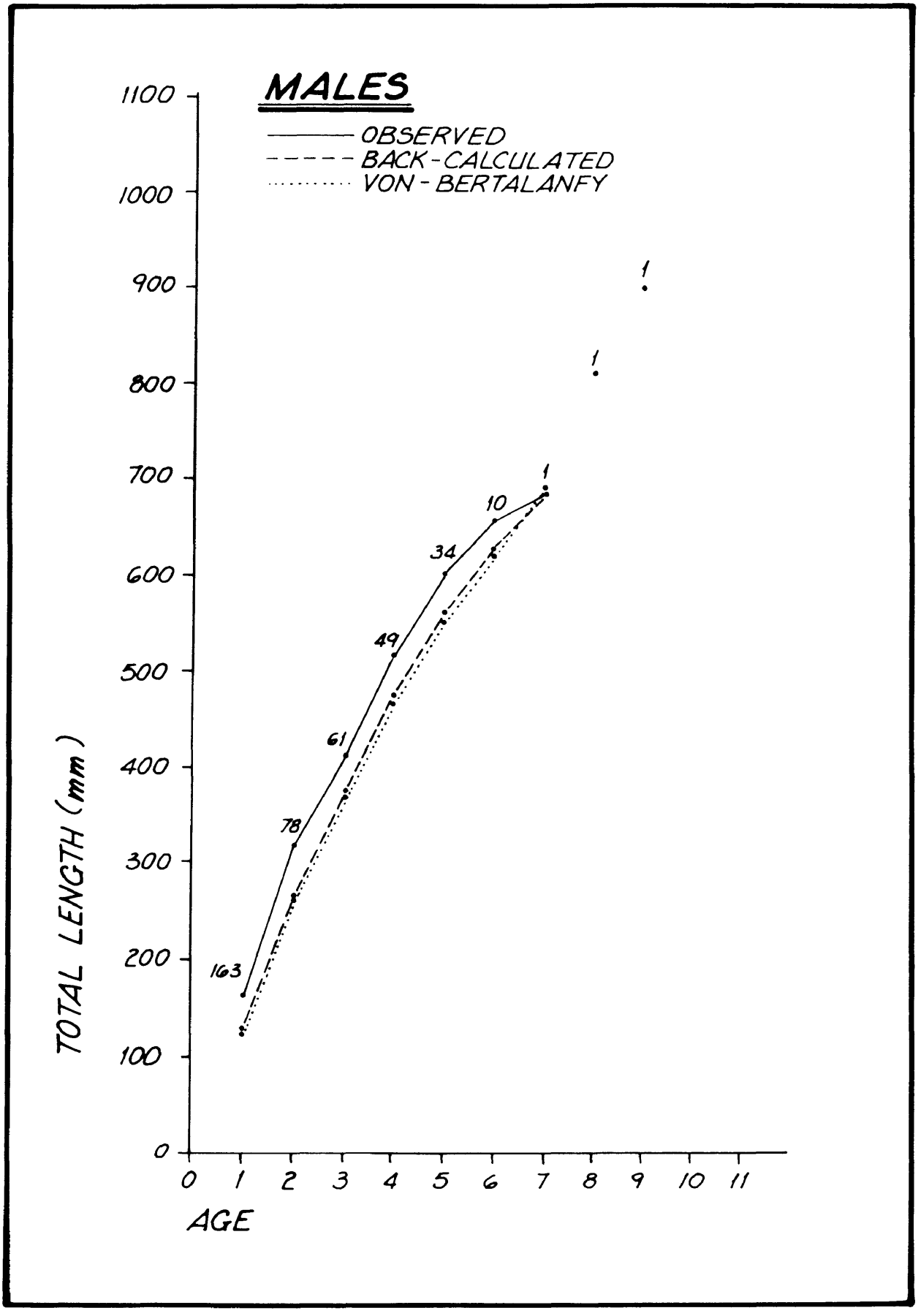

MALES
OBSERVED
BACK-CALCULATED
VON-BERTALANFY
TOTAL LENGTH (mm)
AGE
1100
1000
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11
163
78
61
49
34
10
1
1
1

Figure 16a. Plot of observed lengths with mean, range, and 95% C.I.-Females.

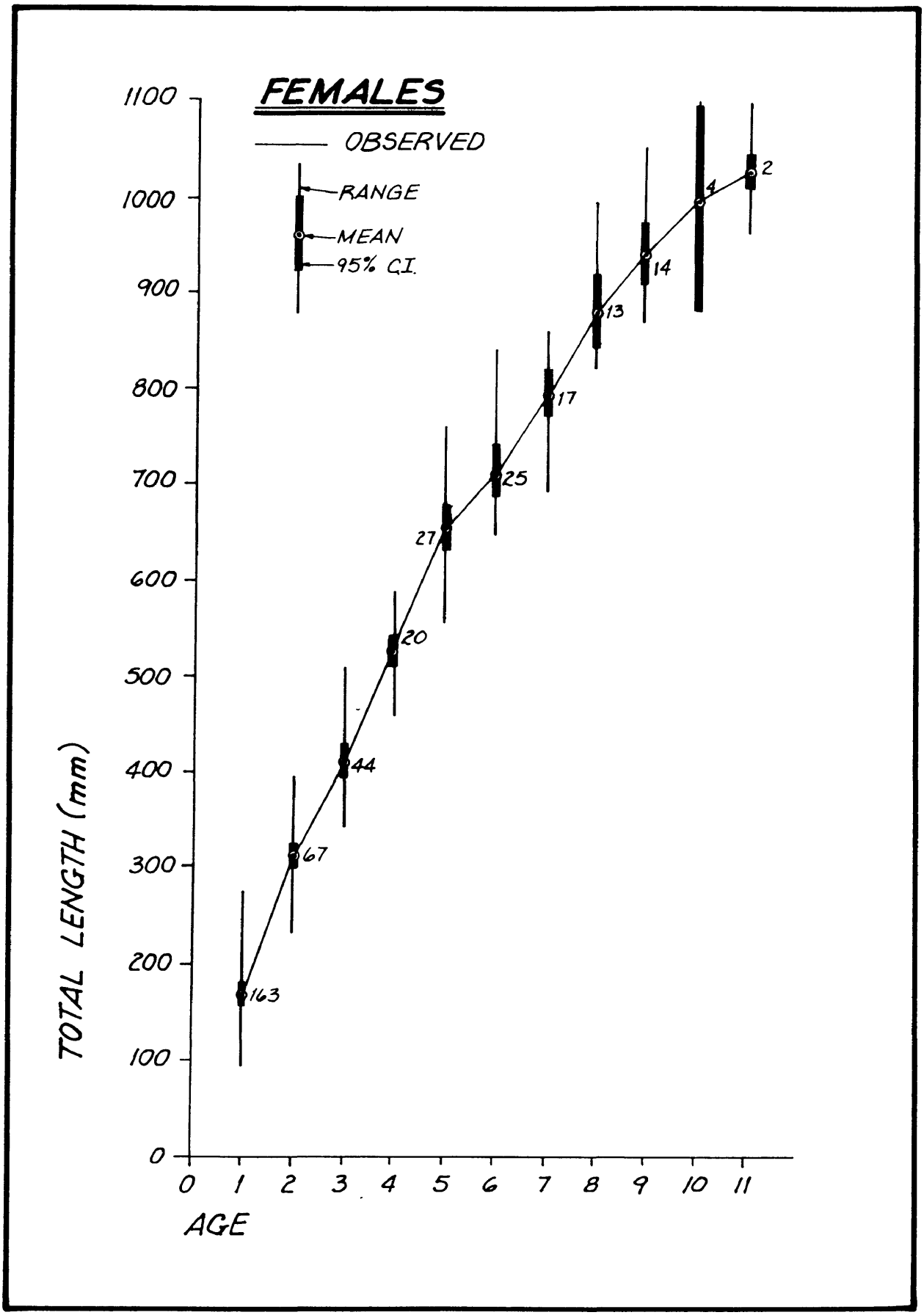
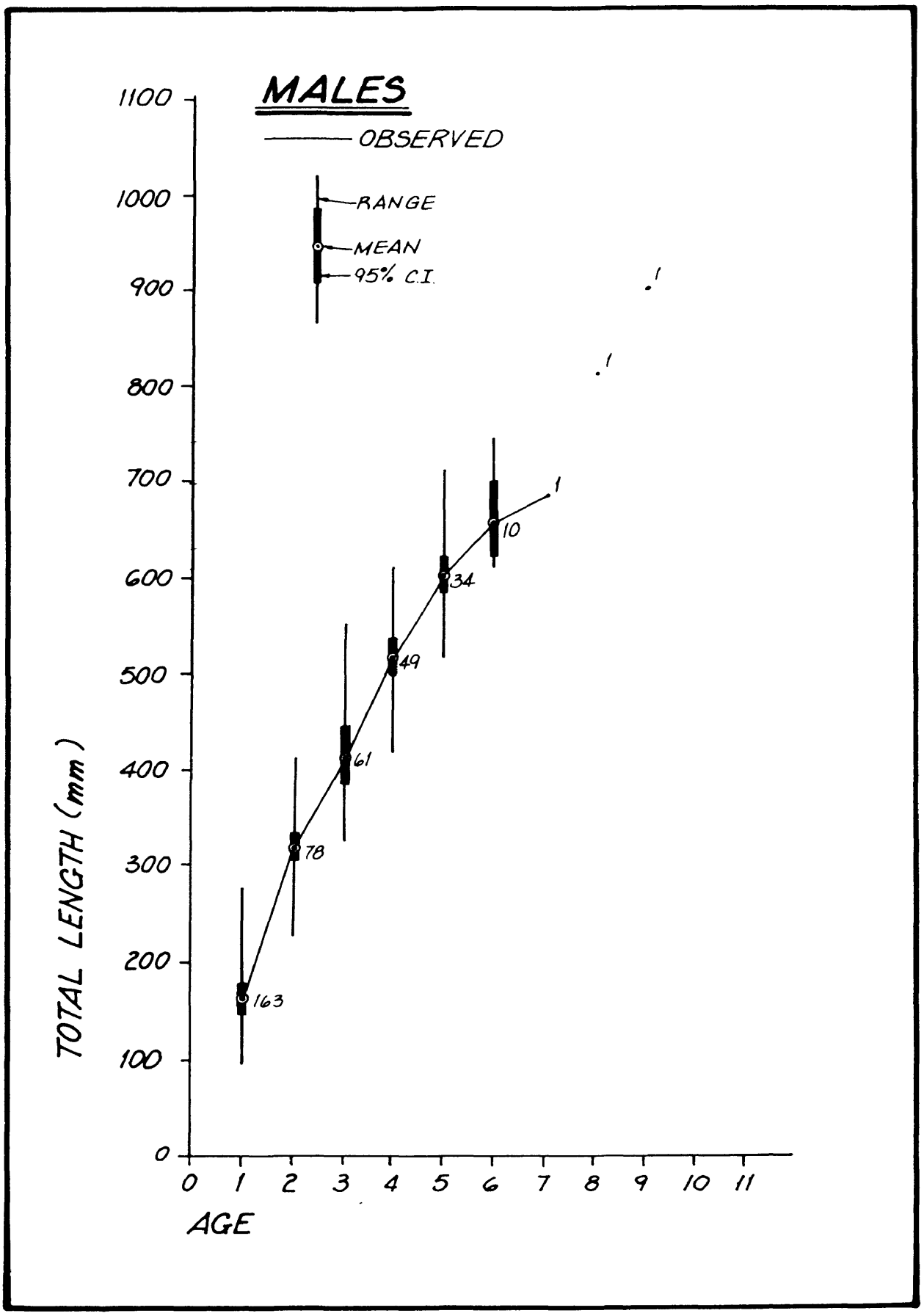

FEMALES
OBSERVED
RANGE
MEAN
95% CI.
TOTAL LENGTH (mm)
AGE
1100
1000
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11
163
67
44
20
27
25
17
13
14
4
2

Figure 16b. Plot of observed lengths with mean, range, and 95% C.I.-Males.


MALES
OBSERVED
RANGE
MEAN
95% C.I.
TOTAL LENGTH (mm)
AGE
1100
1000
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11
163
78
61
49
34
10
1

from each of the age groups, 7, 8, and 9 was captured during the course of this study. The oldest female sampled was eleven years old. Fifty females greater than six years old were obtained. It appears that the number of older males is much fewer than females, indicating greater mortality of the males.

Theoretical Growth

The mean back-calculated lengths-at-age were used to formulate the von Bertalanfy growth equations. Standard methods using Walford plots and regressions of ln ($L_\infty - L_t$) on age were employed to estimate the parameters of the equation. The resulting parameters and equation for females are:

$$K = 0.095$$

$$L_\infty = 1576 \text{ mm}$$

$$t_o = 0.162$$

$$L_t = 1576.0 \left(1-e^{-0.095(t-0.162)} \right)$$

The growth equation for males was calculated using three slightly different data sets. It was first calculated using all the mean back-calculated lengths available. The equation was then formulated after eliminating the two fish in age groups 8 and 9 from the data set and finally it was calculated without age groups 7, 8, or 9. Because there was only one individual in each of these three oldest age

groups, it was felt these were possibly not good estimates of length for these ages. The parameters and equations are as follows:

All males

$K = 0.097$

$L_{\infty} = 1460.0$

$t_o = 0.015$

$$L_t = 1460.0 \left(1-e^{-0.097(t-0.015)} \right)$$

Age groups 8 and 9 eliminated

$K = 0.166$

$L_{\infty} = 1018.0$

$t_o = 0.211$

$$L_t = 1018.0 \left(1-e^{-0.166(t-0.211)} \right)$$

Age groups 7, 8, and 9 eliminated

$K = 0.157$

$L_{\infty} = 1059.0$

$t_o = 0.196$

$$L_t = 1059.0 \left(1-e^{-0.157(t-0.196)} \right)$$

Length-Weight

Equations describing the length-weight relationship were calculated for 305 males and 311 females. The results are presented below and in Figure 17.

Males

$$\log_{10} W = 2.833 (\log_{10} T.L.) - 4.347$$

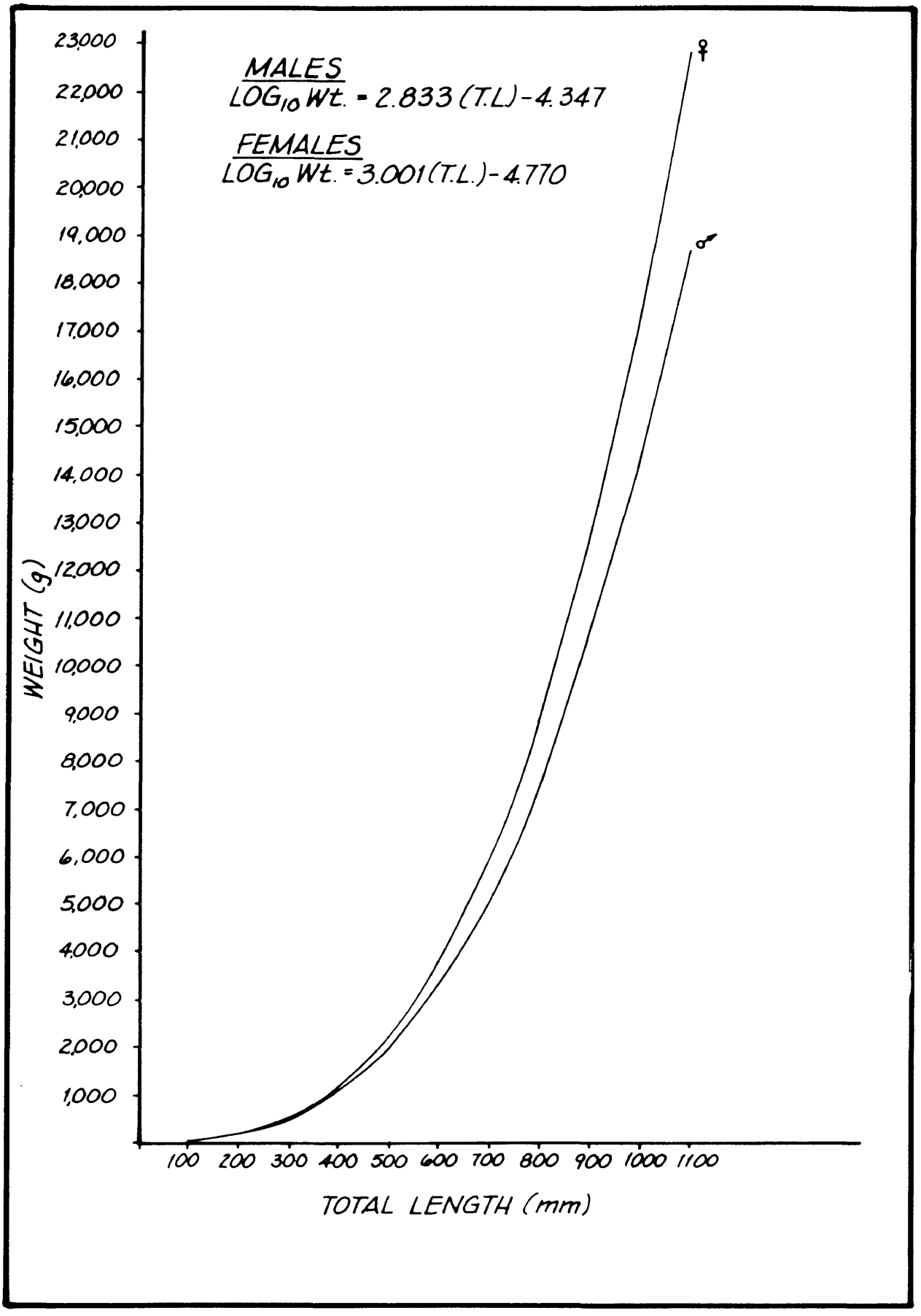
$$R^2 = 0.95$$

Females

$$\log_{10} W = 3.001 (\log_{10} T.L.) - 4.770$$

$$R^2 = 0.98$$

Figure 17. Plot of length-weight relationship.


MALES
LOG10 Wt. = 2.833 (T.L) - 4.347
FEMALES
LOG10 Wt. = 3.001 (T.L.) - 4.770
♀
♂
WEIGHT (g)
23,000
22,000
21,000
20,000
19,000
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
100 200 300 400 500 600 700 800 900 1000 1100
TOTAL LENGTH (mm)

DISCUSSION

Food Habits

The feeding behavior of lophiid anglerfishes has been well documented by several authors (Bigelow and Welsh, 1925; Chadwick, 1929; Wilson, 1937: Gudger, 1945). Lophiids make use of their angling apparatus to attract prey to the vicinity of their mouths. They also engulf prey which strays close enough without using the angling apparatus.

Previous studies have shown that fish make up a large part of the goosefish diet and that they prey on a large number of species. The following species have been found in the stomachs of goosefish from the Gulf of Maine: " spiny dogfish, skates ..., eels, launce, herring, alewives, menhaden, smelts, mackeral, weakfish, cunner, tautog, seabass, butterfish, puffers, various sculpins, sea ravens, sea robins, sea snails, silver hake, tomcod, cod, haddock, hake, witch flounders, American dab, yellowtail flounders, winter flounders, and various other species of flatfish

unnamed, as well as its own kind " (Bigelow and Schroeder, 1953). Connolly (1920) and Leim and Scott (1966) report similar prey species occurred in goosefish from Canadian waters. All these papers also report that goosefish consume invertebrates but in lesser amounts than fish. Lobsters, several species of crabs, squids, annelid worms, shellfish, starfish and sand dollars have all been reported.

Other papers have presented the food habits of goosefish more quantitatively. Maurer and Bowman (1975) showed that fish comprise 85.2% (by weight) of stomach contents. Important prey items included goosefish (14.7%), gadids (22.5%), Atlantic mackeral, Scomber scombrus (7.5%), and flatfish (4.8%). Various squids (12.1%) were the only important invertebrate prey. Bowman et al. (1976) presented data broken down into the following geographic regions : Middle Atlantic, Southern New England, Georges Bank, Gulf of Maine, and Western Nova Scotia. Percent (by weight) of fish in the diet was 66.4, 63.2, 97.2, 92.9, and 99.7 for each area respectively, indicating a somewhat less piscivorous diet in the more southern regions. The decrease in the percentage of fish was due primarily to an increase in the amount of "cephalopods" (presumably squid) consumed (30.0, 28.2, 2.4, 6.0, and 0% for each area respectively). Sedberry (1983) sampled goosefish from the Middle Atlantic Outer Continental Shelf. He found that goosefish fed mainly on fishes and to a lesser extent on benthic invertebrates during all seasons. Decapods and cephalopods were much less

important as food, and polychaetes, amphipods, asteroids, and chaetognaths were only occasionally found in stomachs. Larger goosefish were found to eat larger fish. The most important invertebrates were long-finned squid, Loligo pealeii, and red shrimp, Dichelopandalus leptocerus. Red hake, Urophycis chuss, and unidentified teleost remains were the most important piscine prey items. Sedberry further analyzed the food habit data by partitioning it into groups based on the standard length of the goosefish examined (1-100, 101-200, 201-300, 301-400, 401-500, and >500 mm). He found that goosefish greater than 400 mm S.L. preyed exclusively on fish. A small amount of chaetognaths was found in the 1-100 mm size class and relativley small amounts of decapods and cephalopods were found in goosefish from 101-400 mm S.L., however, fish were by far the dominant prey item in these size groups also.

The results of the present study are in agreement with data presented in the literature. Goosefish prey primarily on demersal/benthic fishes. They appear to be feeding opportunistically on whatever fish species is abundant in a particular area. Red hake are particularly important in the goosefish diet. Because red hake are demersal and actively forage on the bottom, and are abundant in most of the regions occupied by goosefish, they are ideally suited as prey items for the angling/ambush method of feeding exhibited by the goosefish.

Goosefish exhibit an ontogenetic shift away from the consumption of invertebrates as they grow larger. This is due to the fact that most demersal invertebrates (e.g. Dichelopandalus leptocerus) are small and therefore are not preferred food items for larger goosefish since they tend to feed on larger prey items (Sedberry, 1983). An exception to this would be long-finned squid, L. pealeii, which grow to a relatively large size, and were preyed on by all sizes of goosefish in this study. Another difference in food habits between small and large goosefish is feeding frequency. Goosefish in the 1-200 mm size class feed more often than the larger fish as evidenced by their higher percentage of stomachs containg food. This greater feeding frequency is related to higher energy demands resulting from rapid growth during this period of their life history.

Although a variety of benthic invertebrates have been reported as food items (e.g. annelid worms, shellfish, starfish, sand dollars) I agree with Caruso (1977) in concluding that these probably represent net feeding. Caruso states, " the projecting lower jaw, upwardly directed mouth, and long sharp teeth of a lophiid are ill-suited for sampling the benthos, and I can hardly imagine starfish, sand dollars, snails, and clams striking voraciously at a rapidly moving lure." Birds have also been noted as prey items (Bigelow and Schroeder, 1953; Leim and Scott, 1966; Groves and Peabody, 1975; Banta, 1941) including loons, gulls, and ducks. These birds were presumably captured

while floating on the surface in shallow water. While feeding on birds is probably a very rare event, it can be taken as further evidence of the opportunistic nature of goosefish feeding.

Reproduction

All female members of the Lophiiformes are thought to expel non-adhesive, mucoid egg rafts or veils with the possible exception of one species of antenariid angler fish (Pietsch and Grobecker, 1980). These veils are buoyant and have a complex structure consisting of individual chambers which each contain one to three eggs and an opening providing water circulation (Fulton, 1898; Gill, 1905; Rasquin, 1958; Ray, 1961). This method of egg production appears to be unique among the fishes.

The goosefishes, Lophius sp., have the most spectacular egg veils due to their large size. The egg veil of Lophius americanus can reach 6-12 m in length and 0.15-1.5 m in width (Martin and Drewy, 1978). Several authors have provided detailed description of the egg veils of L. americanus (Agassiz and Whitman, 1885; Connolly, 1920; Dahlgren, 1928; and others) and L. piscatorius (Fulton, 1898; Bowman, 1919).

The ovaries of L. americanus were found to contain large numbers of ova (301,150-2,780,632). The number of ova increased linearly with the length of the females. The coefficient of determination (0.67) indicates that

approximately one-third of the variation is unaccounted for by the regression. Possible sources of this variation include errors in the weight of the ovaries (due to the inaccuracy of weight measurements while on-board vessels) and environmental factors, especially availability of food (Moyle and Cech, 1982).

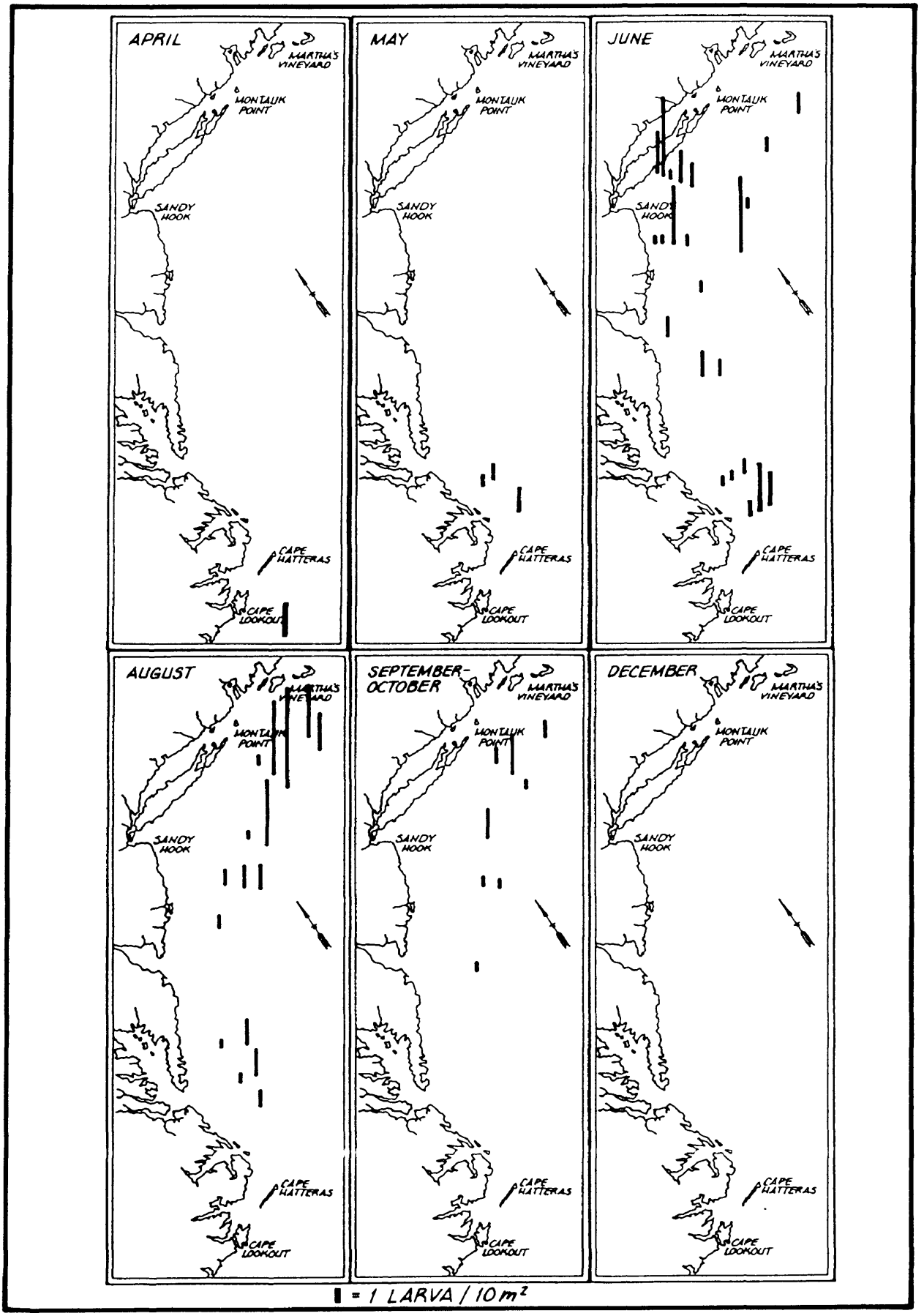
Estimates of fecundity presented by other authors are similar to those obtained in this study. Eaton et al. (1954) estimated 543,000 ova in the ovary of a 660 mm specimen. The regression of fecundity on total length presented here predicts 563,000 ova for a female of this size. Other estimates of fecundity range from 432,000-2,670,000 eggs based on the examination of veils released from females of unknown size (Baird, 1871; Nichols and Breder, 1927; Berril, 1929).

Female goosefish matured at a larger size and at a greater age (487 mm, age 4) than males (369mm, age 3). This is a common trend among teleosts (Moyle and Cech, 1982). In the case of goosefish, the female requires a larger body size to accomodate the large egg veil. Connolly (1920) was unable to determine the size at maturity due to a very small sample size but he states that a goosefish eighteen inches (457 mm) long (unstated sex) was immature and all individuals over 31 inches (787 mm) were mature. McBride and Brown (1980), in a tabular summary of life history parameters for several demersal fish species, present the age at maturity for L. americanus as 4 and 5 years for males

and females, respectively. The source of their data is not stated. Martin and Drewry (1978) and several others also suggest that the age of maturity is 4 and 5 years for males and females. However, they state the source of this information as Connolly (1920). A review of Connolly's paper shows that he was quoting a publication by Fulton (1903), which deals with the growth of L. piscatorius, not L. americanus . At the time of Connolly's paper, the two species were considered synonymous. However, because L. piscatorius is known to reach a larger maximum size and is larger at each age (based on data presented in the following age and growth discussion), the age at maturity can not be considered the same for the two species. In fact, it would be expected that the age and length at maturity for L. piscatorius would probably be greater, as suggested here.

Data on gonad condition and the gonasomatic index indicate that spawning takes place in May-June in the area from Cape Hatheras to Southern New England. Because samples were collected and pooled from throughout this entire region, a seasonal progression of spawning from south to north as suggested in the literature can not be demonstrated. Data on goosefish larval distribution collected by NMFS in this area during 1965-1966 (Berrien et al., 1978) indicate that the majority of spawning takes place in late May and June (see Figure 18) assuming the eggs hatch in one to three weeks (Berrill, 1929; McKenzie, 1936; Leim and Scott, 1966). These data also show a progression

Figure 18. Temporal distribution of larvae of L. americanus.


APRIL
MAY
JUNE
AUGUST
SEPTEMBER-
OCTOBER
DECEMBER
MARTHA'S
VINEYARD
MONTAUK
POINT
SANDY
HOOK
CAPE
HATTERAS
CAPE
LOOKOUT
▮ = 1 LARVA / 10 m²

of spawning from south to north with time. This suggests that water temperature and photoperiod are the environmental factors which induce maturation of the gonads.

Testes appear to develop earlier and remain ripe longer than ovaries. Fulton (1898) found the same to be true for L. piscatorious. This suggests that males may be multiple spawners. Multiple spawning in males would increase the chances of a ripe female encountering a ripe male, and thereby spawning successfully. It also serves to equalize the energetic investment of the sexes in reproduction. It appears that the investment of females is relatively high. The gonasomatic index was as high as 50%. Tsimenidis (1980) found values as high as 37% for the Mediterranean goosefish, L. budegassa. A large part of the ovarian weight is composed of the muco-gelatinous material which forms the veil. The caloric value of this material is unknown but probably is rather low due to its low density and apparently high water content. However, the large amount of this material combined with the great number of eggs produced represents a sizeable energetic contribution by the female to reproduction.

Histological examination of the goosefish testes showed that spermatogenesis and the internal structure are not remarkably different from other teleosts. It also confirmed the validity of macroscopic staging of testes in the field. Examination of ovaries showed that oogenesis is similar to other teleosts but the structure of the ovary is somewhat

different. The most significant differences were the presence of stalk-like lamellae containing the developing ova, and epithelium lining the lumen which is responsible for secreting the muco-gelatinous matrix. Fulton (1898) was the first to suggest this mechanism of veil formation in the Lophiids. His figures and descriptions of the histology of the ovaries of L. piscatorius indicate they are identical to those from L. americanus, seen here. Rasquin (1958) provided detailed descriptions and photographs of the ovaries of two species of antennariid anglers (Antennarius, Histrio) and one species of Ogcocephalid angler. These lophiiform species are known to produce egg veils. Although they are all only a fraction of the size of L. americanus and L. piscatorius, the histology of their ovaries was virtually identical to their larger relatives including the presence of stalk-like ovigerous lamellae and secretory epithelium. It is reasonable to assume that all members of the order Lophiiformes known to produce egg veils have similar ovaries. This character may be useful in verifying veil production in some of the deep water lophiiform families for which veil production has been assumed but not verified.

Pietsch and Grobeck (1980) suggest that the egg veil is an excellent device for broadcasting a large number of eggs over great geographical distances. In addition, the buoyancy of the veil causes the eggs to develop in relatively productive surface waters. There seem to be

additional selective advantages to the egg veil as well. It may function in facilitating fertilization of the eggs. When a veil is first extruded from the female, it absorbs a large quantity of water. As water is absorbed, sperm may be drawn into the egg chambers through the small circulation pores in the veil, thereby insuring fertilization.

The veil likely functions in the protection of the eggs and embryos (since the embryos remain in the egg chambers for 2-3 days after hatching (Dahlgren, 1928)) by several methods. Predators such as zooplankton are physically excluded from the egg chambers by the small size of the circulation pore. The veil may reduce or eliminate olfactory cues, thereby eliminating predators locating food items by this method. Wells (1977) suggests that the jelly coat of yellow perch (Perca flavescens) spawn may act in a similar manner. Finally, the muco-gelatinous material of goosefish egg veils may be toxic or repugnant to potential predators. Newsome and Tompkins (1985) found that the egg mass of yellow perch contain some compound(s) that are not toxic but seem to deter predators. While such a protective device is rare among the teleosts (Fuhrman et al. 1969; Orians and Janzen, 1974), the presence of toxic or unpalatable compounds within the jelly coat of amphibian egg masses is well known (Licht, 1969; Ward and Sexton, 1981).

Age and Growth

Females and males have about the same weight at length before maturity. After maturity the females are slightly heavier than males, due to their large ovaries. As the ovaries ripen the weight differences between males and females becomes greater. The regression slopes for males and females approximate 3, implying isometric growth in the length-weight relationship. Tsimendis and Ondrias (1980) calculated very similar length-weight regressions for L. piscatorius in the Mediterranean Sea.

Vertebrae appear to be valid aging tools for L. americanus . They satisfy all of Van Oosten's (1929) criteria. Vertebrae are easy to locate and remove from fish and are relatively easy to prepare and read. The annuli are relatively easy to discern since only 3% of the vertebrae were considered unreliable and an inexperienced, independent reader agreed with the counts in 80% of the readings he performed.

The data indicate that the annuli are laid down in May. Because these rings are present on juveniles as well as adults, they appear to be related to seasonal patterns of growth rather than reproduction. The annuli are difficult to see when they are at the very edge of the vertebral centra. For this reason thay are probably not detected until some additional growth has occured after they are laid down. Yasudo (1940) has shown that on vertebrae of

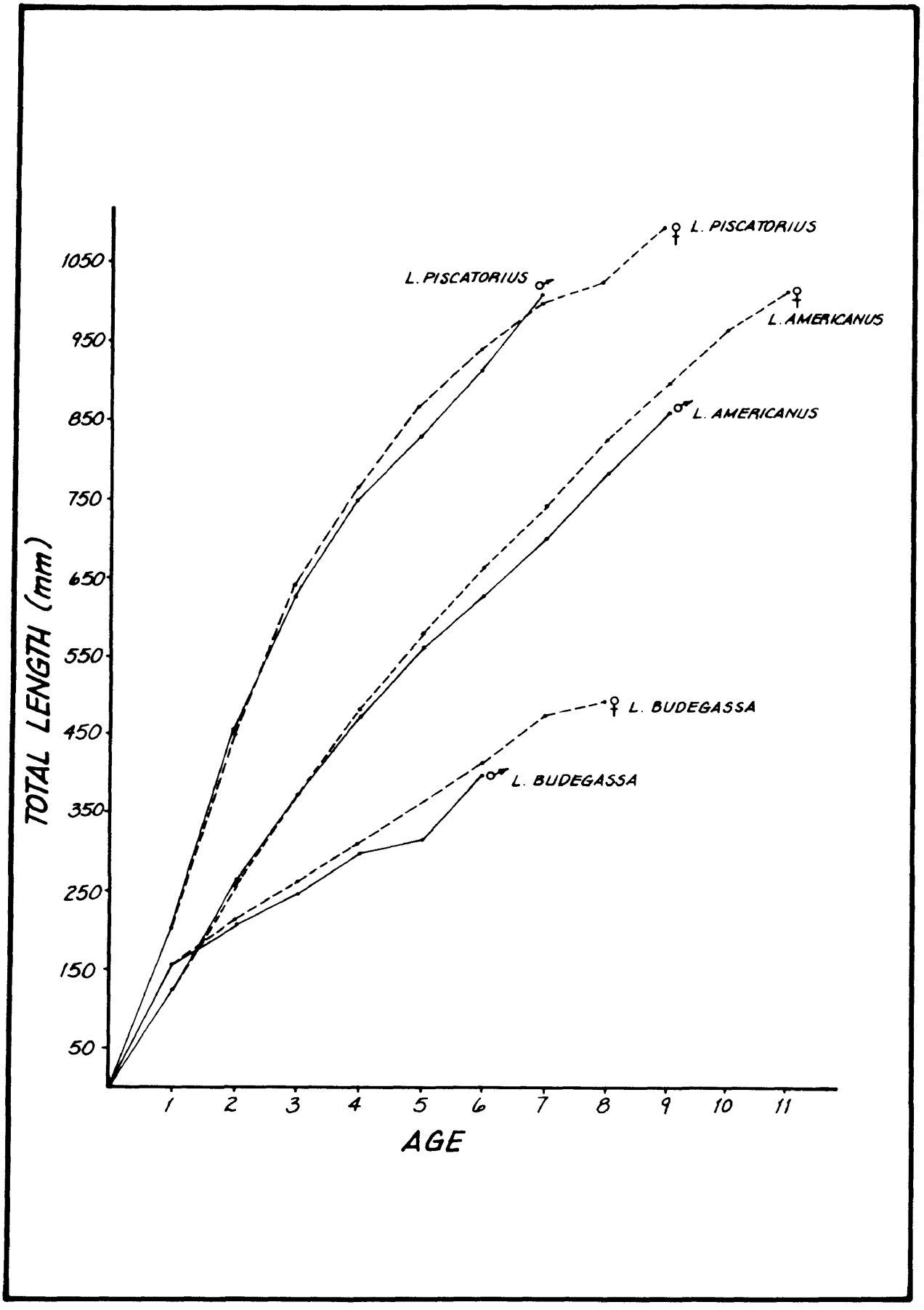
Scombrops sp. annuli were formed 1.5 months later than on the otoliths. So it is likely that the annuli (composed of a step and a translucent band) found on goosefish vertebrae represent the end of fast growth (the step) in late fall and a period of slow winter growth (the translucent band).

While several authors have studied growth in L. piscatorius and L. budegassa (Fulton, 1903; Guillou, 1978; Tsimenidis and Ondrias, 1980), only Connolly (1920) has looked at growth in L. americanus. He based his growth estimates on vertebral annuli counts but his sample size was only six individuals. His results were as follows: age 1-114mm, age 4-457mm, age 8-737mm, age 9-787mm, age 10-940mm, age 12-1016mm. These estimates are slightly lower than found in this study, but a slower growth rate would be expected in the colder Canadian waters in which Connolly conducted his study.

The growth rate of L. americanus is intermediate to L. piscatorius and L. budegassa. Figure 19 compares the mean back-calculated lengths for the two european species (from Tsimenidis and Ondrias, 1980) with data presented here for L. americanus.

The differences in observed and back-calculated mean lengths between males and females past age 4 are small but appear to be real. This is the most common form of sexual dimorphism among fishes (Moyle and Cech, 1982). Tsimenidis and Ondrias (1980) found similar small differences between the sexes for L. budegassa and L. piscatorius.

Figure 19. Plot of back-calculated lengths for three lophiid species.


TOTAL LENGTH (mm)
1050
950
850
750
650
550
450
350
250
150
50
1
2
3
4
5
6
7
8
9
10
11
AGE
♀ L. PISCATORIUS
L. PISCATORIUS ♂
♀ L. AMERICANUS
L. AMERICANUS ♂
♀ L. BUDEGASSA
L. BUDEGASSA ♂

More significant is the difference in mortality between the sexes implied by the data. The heavier mortality of males may be caused by increased predation due to their smaller size but this does not seem likely. Perhaps the males exhibit behavioral or distributional differences which make them more susceptible to predation or fishing effort. A final possibility is that they simply reach senescence before females.

The von Bertalanfy growth equations fit the back-calculated lengths extremely well. The values for L_{∞} for both sexes seem somewhat inflated. The maximum reported size for L. americanus is approximately 1220 mm (Bigelow and Schroeder, 1953). The largest female collected in this study was 1115 mm and the calculated L_{∞} was 1576 mm. The largest male collected was 900 mm compared to a calculated L_{∞} ranging from 1018 to 1460 mm. The inflation of L_{∞} is caused by a lack of representatives from the older age classes. This is a common problem in age and growth studies. The asymptotic length is therefore not well defined for either sex in this study. The sampling effort was believed to be intense enough to sample these larger individuals if they were present in the population. It is concluded that these individuals are simply not present. This is very likely the result of commercial fishing pressure (groundfishing and scalloping), which tends to be selective towards larger individuals.

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